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THE UNIVERSITY OF ALBERTA

ACCUMULATION AND ADSORPTION CAPACITY OF POWDERED ACTIVATED CARBON IN A SLURRY RECIRCULATING CLARIFIER

BY

KARIM KASSAM

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

IN

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DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled: ACCUMULATION AND ADSORPTION CAPACITY OF POWDERED ACTIVATED CARBON IN A SLURRY RECIRCULATING CLARIFIER submitted by KARIM KASSAM in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

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ABSTRACT

In drinking water treatment, fixed bed granular activated carbon (GAC) adsorbers are commonly used to remove organic compounds of potential health concern. The application of powdered activated carbon (PAC) has been limited because of the assumption that large dosages are necessary. In recent years, special applications of PAC have been investigated as an alternative to GAC in an effort to reduce the cost for removal of organics. One application of PAC that has received little attention is its use in a solids contact slurry recirculating clarifier (SCSRC), where it is believed high concentrations of PAC can be accumulated. The high concentration in combination with the recycle process could result in enhanced organic removal. The objective of this research was to examine the accumulation and adsorption capacity of PAC in a SCSRC.

A pilot scale water treatment plant with two SCSRCs was operated to run in parallel with the full scale, City of Edmonton's E.L. Smith Water Treatment Plant.

A method to determine PAC concentration in the clarifier slurry had to be developed. This new method was based on a gravimetric analysis approach. Isotherms to measure the adsorption capacity for a specific compound (chloroform) of the PAC containing slurry were performed using a modification of the bottle point method.

Four experimental runs were carried out. The objectives of the individual runs were to monitor accumulation of PAC in a SCSRC and determine reproducibility, study the impact of increasing PAC feed

rate on the steady state concentration of PAC, and evaluate the residual adsorption capacity of PAC accumulated in the SCSRC.

The principal findings of this study are:

(i) Very high concentrations of PAC (>4000 mg/L) could be achieved in a SCSRC. The accumulated concentration is dependent on the PAC feed rate;

(ii) Influxes of high turbidity raw water (100-450 N.T.U.) reduced substantially the PAC concentration because of the need for increased sludge wasting;

(iii) The concentration of PAC is evenly distributed through the entire SCSRC with the exception of the settling area above the tube settlers; and

(iv) The adsorptive capacity for chloroform of the slurry containing PAC appears to decrease somewhat with increase in PAC residence time in a SCSRC.

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TABLE OF CONTENTS

CHAPTER		PAGE
1.	INTRODUCTION	1
2.	OBJECTIVES AND EXPERIMENTAL APPROACH	4
3.	TECHNICAL BACKGROUND	5
	3.1 Organics in Drinking Water	5
	3.2 Organic Removal Processes	5
	3.3 Carbon Adsorption	6
	3.4 Factors Affecting Carbon Adsorption	7
	3.5 Adsorption Kinetics	10
	3.6 Powdered versus Granular Activated Carbon	12
	3.7 PAC Special Applications	15
	3.8 Summary and Research Needs	17
4.	PILOT PLANT COMMISSIONING AND OPERATION	19
	4.1 Pilot Plant Process Schematic	19
	4.2 Pilot Plant Commissioning and Operation	19
	4.2.1 Clarifier Design	25
	4.2.1.1 Inlet Pipe	25
	4.2.1.2 Sample Points	25
	4.2.1.3 Rapid Mixing	27
	4.2.2 Plant Hook-up and Preparation	27
	4.2.2.1 River Water Source	27
	4.2.2.2 Power Source	28
	4.2.2.3 Winterizing	28
	4.2.3 Plant Start-up	28
	4.2.3.1 Solids Slurry	29

4.2.3.2 Coagulant Selection 30
4.2.3.3 Carbon Feed System 32
4.2.4 Performance Comparisons 34
4.2.4.1 Tracer Studies 34
4.2.4.2 E.L. Smith vs. Pilot Plant 36
4.3 Pilot Plant Process Routine Operation 36
5. METHODS AND MATERIALS 42
5.1 Methods for Laboratory Analysis 42
5.1.1 Carbon in Clarifier Slurry 42
5.1.1.1 Basis for Method Development 42
5.1.1.2 Method Concerns and Solutions 43
5.1.1.3 Method 46
5.1.2 Carbon Isotherms 52
5.1.2.1 Bottle Point Method 52
5.1.2.2 Modified Bottle Point Method 54
5.1.3 Chloroform Analysis 55
5.1.4 Quality Assurance and Control. 55
5.2 Methods for Routine Plant Operations 59
5.2.1 Turbidity 59
5.2.2 pH 59
5.2.3 V/V Solids Percent 60
5.2.4 Chemical Feed Confirmation 60
5.2.5 Clarifier Seeding 60
5.3 Materials 62
5.3.1 Carbon 62
5.3.2 Aluminex^{R} 62

5.3.3 Polymer 62
5.3.4 Chloroform 62
6. PILOT PLANT EXPERIMENTAL DESIGN 63
7. RESULTS 65
7.1 Carbon Accumulation 65
7.1.1 PAC Concentration in Clarifier Slurry. 65
7.1.2 Clarifier Draining 74
7.1.3 Influent Turbidity 74
7.1.4 Recirculator Speed 77
7.1.5 Mean PAC Retention Times 77
7.1.6 PAC Profile in Clarifier 80
7.2 Chloroform Analysis 80
7.2.1 Isotherm for PAC in River Water. 80
7.2.2 Isotherms for Clarifier Slurry with PAC. 83
7.2.3 Effects on PAC Adsorption Capacity 83
7.2.3.1 Sampling Days 83
7.2.3.2 Mean PAC Retention Times 89
7.2.3.3 PAC Background Organic Exposure. 92
8. DISCUSSION AND IMPLICATIONS 98
9. CONCLUSIONS 103
10. RECOMMENDATIONS 105
REFERENCES 107
APPENDIX I 111
APPENDIX II 115
APPENDIX III 118
APPENDIX IV 138

LIST OF TABLES

TABLE #	DESCRIPTION	PAGE
I	Freundlich Isotherm Constants for Trihalomethanes....	9
II	Freundlich Isotherm Constants for Chloroform at Various Pre-loading Times.....	11
III	Pilot Clarifier Operating Specifications	23
IV	Summary of Clarifier Residence Times	38
V	Comparison of Operating Data - Pilot Plant vs E.L. Smith Plant	39
VI	Pilot Plant Operating Log Sheet.....	41
VII	Effect of Carbon Analysis Steps on Individual Slurry Constituents	45
VIII	Comparison of PAC Concentrations - Actual vs Measured	47
IX	GC Operating Parameters.....	56
X	GC Clean Out Procedure.....	57
XI	Pilot Plant Experimental Design Summary	64
XII	Mean PAC Retention Times in Slurry	81
XIII	Summary of Isotherm Correlation Factors 101	

LIST OF FIGURES

FIGURE	DESCRIPTION	PAGE
1	Breakthrough Curve Through a Column Adsorber	13
2	Concentration Profile through Reactor Systems	14
3	Layout of Mobile Water Treatment Plant	20
4	Mobile Water Treatment Plant - Process Schematic	21
5	Pilot Clarifier - Cross-Section	22
6	Pilot Plant - Parallel Flow Arrangement	24
7	Pilot Clarifier - Inlet Pipe Modifications	26
8	Coagulants - Effect on Clarifier Performance	31
9	Pilot Plant - Carbon System Modifications	33
10	Response Curve in Clarifiers to Tracer Step Input	35
11	Response Curve in Clarifiers to Tracer Pulse Input	37
12	Pictorial Representation of Carbon Determination Analysis	44
13	Box Diagram to Illustrate PAC Determination in Slurry Samples	51
14	PAC Concentration in Slurry - Experimental Run No.1	66
15	PAC Concentration in Slurry - Comparison of Experimental Run No.1 and 2	68
16	PAC Concentration in Slurry - Experimental Run No.2	69
17	PAC Concentration in Slurry - Experimental Run No.3	70
18	PAC Concentration in Slurry - Experimental Run No.4	72
19	Summary of PAC Concentrations in Slurry - All Experimental Runs (1 - 4)	73
20	Impact of Clarifier Draining - PAC Feedrate 10 mg/L	75
21	Impact of Clarifier Draining - PAC Feedrate 25 mg/L	76
22	Influent Turbidity and PAC Concentrations in Slurry	78

23	Impact of Recirculator Speed on PAC Concentration in Slurry	79
24	PAC Profile Through the Clarifier	82
25	Chloroform Isotherm for PAC in River Water	84
26	Chloroform Isotherm Points for Clarifier 1	85
27	Chloroform Isotherm Points for Clarifier 2	86
28	Chloroform Isotherms for Clarifier No. 1 - w.r.t. Experimental Run Time	87
29	Chloroform Isotherms for Clarifier No. 2 - w.r.t. Experimental Run Time	88
30	Chloroform Isotherms for Clarifier No. 1 - w.r.t. Experimental Run Time and Showing PAC Retention Time	90
31	Chloroform Isotherms for Clarifier No. 2 - w.r.t. Experimental Run Time and Showing PAC Retention Time	91
32	Chloroform Isotherms for Clarifier No. 1 - Regrouped with Respect to PAC Retention Time	93
33	Chloroform Isotherms for Clarifier No. 2 - Regrouped with Respect to PAC Retention Time	94
34	Chloroform Adsorption Capacity vs Mean PAC Retention Times - Clarifier No. 1 & No. 2	95
35	Chloroform Adsorption Capacity vs Background Organic Exposure Factor - Clarifiers No. 1 & 2	96

CHAPTER 1: INTRODUCTION

Activated carbon adsorption has been the process of choice for taste and odour control in the treatment of drinking water for over 50 years. In the last decade, with the technological advancement made in the area of chemical analysis, the identification of organic contaminants at trace levels has provided a more accurate assessment of the performance characteristics of adsorption systems. Carbon adsorption has proven to be one of the most efficient methods for removing organic contaminants at trace levels.

The application of Powdered Activated Carbon (PAC) for organics control has been limited because of the assumption that large dosages are necessary. Cost factors have therefore, favoured the use of granular activated carbon (GAC) in columnar systems with regeneration and reuse of the carbon. In recent years, special applications of PAC have been investigated (the Roberts-Haberer Process at Virginia Polytechnique and the fluidized bed reactor at the University of Illinois) as alternatives to GAC with a view to reducing the cost of the removal of organics. One particular application of PAC that has received little attention is its use in a solids contact slurry recirculating clarifier (SCSRC). Several clarifiers of this type are available under various proprietary names. In an SCSRC, PAC could be accumulated in the floc, thus increasing the carbon concentration. The higher concentration in combination with the recycle process will increase the effective carbon dosage and the contact time, and should enhance organic removal.

If research on PAC addition in a SCSRC were to confirm that considerable quantities of PAC could be retained and provide enhanced contact, this could lead to a cost effective alternative to GAC under specific treatment requirements, i.e. seasonal or intermittent presence of organics.

Many communities in North America currently use the solids contact clarifiers process in the treatment of drinking water and some of these face seasonal organic problems. The City of Edmonton is one such community. During spring thaw, in most years, the North Saskatchewan River (the source of drinking water in Edmonton) is subjected to short term excessively high loadings of organic matter. The current practice of low level PAC addition during problem periods fails to provide the effective removal of these organics, resulting in taste and odour in the drinking water. The City stands to benefit from research that can confirm a cost effective use of PAC to deal with its seasonal organics problems. Studies to date have not specifically quantified the accumulation and dynamics of PAC in solids contact clarifiers. In addition, a review of the literature indicates that the majority of the work on solids contact clarifiers in drinking water treatment has concentrated on the pulsator type solids contact units and none on the slurry recirculating solids contact units.

The major objectives of this thesis therefore were: (i) to quantify the accumulation of PAC in a slurry recirculating type solids contact clarifier at pilot scale; (ii) to examine the distribution of accumulated PAC through the SCSRC; and (iii) to evaluate the residual capacity of the PAC containing slurry using batch chloroform adsorption

tests under laboratory conditions.

This research provides a preliminary analysis and operating information in examining improved PAC treatment techniques which may prove to be cost effective and efficient in the removal of organic contaminants in drinking water.

CHAPTER 2: OBJECTIVES AND EXPERIMENTAL APPROACH

The overall objective of this study was to examine the accumulation and adsorption performance of the powdered activated carbon in a solids contact slurry recirculating clarifier. The specific activities to meet this objective were:

1. to modify and commission a mobile water treatment pilot plant for the research study;
2. to formulate the pilot plant operating parameters on the basis of: (i) matching the large scale City of Edmonton's E.L. Smith Plant; and (ii) establishing similarity in performance and characteristics of the two pilot plant clarifiers;
3. to develop a method to determine PAC concentration in the clarifier solids slurry;
4. to establish the means of creating a high but reproducible level of PAC accumulation in the pilot scale slurry recirculating clarifier;
5. to examine the distribution of a accumulated PAC in the pilot scale slurry recirculating clarifier; and,
6. to evaluate at bench scale, the chloroform adsorption performance of the carbon containing slurry at various time periods.

To meet the above objectives, four experimental runs were carried out. The details of the experimental runs are described in Chapter 6.

CHAPTER 3: TECHNICAL BACKGROUND

3.1 Organics in Drinking Water

One of the most important aspects in the treatment of drinking water is the removal of organic contaminants. Organics present in water supplies were classified into three main classes by Randtke (1988):

(i) Natural Organic Matter: Usually humic and fulvic substances, microbial exudates and other natural organic materials dissolved into the water from sources such as vegetation, animal wastes, etc.

(ii) Synthetic Organic Matter: Pesticides, herbicides, organic solvents, volatile organic chemicals and other chemicals produced commercially or generated as waste products.

(iii) Treatment Chemicals and By-products: Chemicals that are added or are formed in the water during treatment or in the distribution system, for example aluminum or trihalomethanes (by-product of chlorine reacting with humic substances).

3.2 Organic Removal Processes

Prior to 1970, the issue of organic compounds in drinking water was evaluated mainly in terms of organoleptic criteria, i.e. colour and/or taste and odour. Conventional treatment practices that included coagulation, flocculation, sedimentation, disinfection and filtration were in most cases considered adequate removal processes to meet the organoleptic criteria. However, the technological advances in instrumentation capable of detecting organics at trace levels led to several studies aimed at identification and isolation of specific

organic compounds present in water. Findings from these studies revealed the presence of various organic compounds; Kraybill (1981) cited many of these as potential health hazards.

Advanced treatment methods have since become necessary to address the removal of these organics at trace levels. Ozone oxidation and activated carbon adsorption are the two most effective of these advanced removal processes.

In North America, the move towards introducing advanced treatment methods is only now beginning to gain momentum. In the United States, this is due to the recent introduction of stricter drinking water quality standards for specific parameters (SDWA, 1986). A survey of utilities across the U.S. showed that 25% of these utilities already use PAC for taste and odour control (AWWA Committee Report, 1977). On the basis of this survey, the use of PAC for trace organic removals would therefore be an attractive alternative to GAC adsorbers for these utilities.

3.3 Carbon Adsorption

Adsorption is defined as the increase in concentration of a particular component at the surface or interface between two phases. Adsorption operations exploit the ability of certain solids preferentially to concentrate specific substances from solutions onto their surfaces.

The surface chemistry and pore structure of activated carbon make it an ideal adsorbent for the numerous organic contaminants in water.

Adsorption of organics from aqueous solutions involves concentration

of the solute on the activated carbon surface. During the adsorption process, the sorbed solute tends to desorb into the solution. Equal amounts of solute eventually are being adsorbed and desorbed simultaneously until the rates of adsorption and desorbtion attain equilibrium. Equilibrium can be described mathematically by an adsorption isotherm. Several models can be used for describing adsorption data but the Freundlich adsorption isotherm is one of the most commonly used and is given by:

$$\frac{x}{m} = KC_e^{1/n}$$

x = the amount of solute adsorbed, ug
m = the mass of adsorbent, g
C_e = the solute equilibrium concentration, ug/L
K, 1/n = constant characteristics of the system

3.4 Factors Affecting Carbon Adsorption

Factors that affect adsorption equilibrium are adsorbent characteristics (e.g. surface area and pore structure, particle size, chemistry of the surface); nature of the adsorbate; and aqueous solution chemistry.

The adsorption process results in a concentration of solutes at the surface, therefore the surface area is an important characteristic affecting the adsorptive capacity of an adsorbent. The pore size distribution in activated carbon indicates that micropores contribute a large part of the surface area (Weber, 1972; McGuire and Suffet, 1978). The surface area accessible to the sorbate will be influenced by its molecular size, and only those pores that are accessible to the sorbate will contribute to the effective or measured surface area.

The surface area of non-porous adsorbents increases with a decrease in particle size. However, due to highly porous nature of activated carbon most of the surface area is in the internal pore structure and the surface area would be expected to be independent of the particle size. Studies (Cini et. al., 1980) seem to indicate though, that the breaking up of large carbon particles does serve to open some tiny sealed channels in the carbon that then become available for adsorption.

The presence of specific functional groups on the surface of carbon also affects the adsorption process. Oxidation of the carbon surface with chlorine can reduce the carbon's capacity for phenols (Snoeyink, 1986). The affinity of the adsorbing molecule for water compared to its affinity for the adsorbent is also important. The adsorption of a molecule is also a function of the pH. On the basis of the pH range, a molecule can be neutral or charged. Neutral molecules are adsorbed highly but may be desorbed if the pH range changes to make the molecules charged.

The extent and rate of adsorption on activated carbon also depends on the properties of the adsorbate. Correlations between adsorption capacity and the properties of individual compounds such as: solubility, molecular size and weight, have been found by McCreary and Snoeyink (1980). Table I shows the Freundlich Isotherm constants for four trihalomethanes as reported by Huck and Andrews (1988). The K values for bromoform is more than a order of magnitude greater than that for chloroform.

Various experiments (Zimmer et al., 1987; Najm et. al., 1988; Huck and Andrews, 1988) have also shown that the adsorptive capacity of

TABLE I

COMPOUND	*K* $(ug/g)(L/ug)^{1/n}$		*PAC * Dose (mg/L)*
Chloroform	142.6	0.6624	63.1
Bromodichloromethane	400.8	0.6065	22.5
Dibromochloromethane	800.9	0.5988	11.2
Bromoform	1,792.0	0.5582	5.0

** 90% Reduction (10 ug/L to 1 ug/L) dose calculated*
Carbon: Filtrasorb 300

After: Huck and Andrews (1988)

Table I: Freundlich Isotherm Constants For Trihalomethanes

carbon for a particular compound decreases with the length of time that the carbon has been "pre-loaded" with background organics. Huck and Andrew's (1988) tabulation of Freundlich K for chloroform at various pre-loading times is summarized in Table II. While capacity does not decrease uniformly with preloading time, the trend in the data is clear.

Finally the inorganic composition of water can also contribute towards the extent of adsorption. Inorganic substances such as calcium precipitates may interfere with adsorption if they deposit on the adsorbent (Carns and Stintson, 1978).

3.5 Adsorption Kinetics

The removal of substances from solution in an adsorber involves three consecutive steps. The first step is the transport of the adsorbate from bulk solution to the outer surface of the adsorbent granule by molecular diffusion (film diffusion). The second step involves the transport of the adsorbate from the particle surface into interior sites by diffusion within the pore filled liquid (internal diffusion) and migration along the solid surface of the pore (surface diffusion). The third step is adsorption of the solute on the active sites or the interior surfaces of the pores.

In a turbulent flow reactor such as when PAC is added to a rapid mixer or a flocculator, a combination of film or internal diffusion very often controls the rate of adsorption. If the PAC particle is embedded in a floc particle then probably the rate will be controlled by film diffusion. The rate of diffusion can also be influenced by the adsorption step when competitive adsorption or the presence of

TABLE II

PRE LOADING TIME – Weeks	K $(ug/g)(L/ug)^{1/n}$		PAC * Dose (mg/L)
0	142.60	0.6624	63.1
2	43.84	0.7467	205.3
4	54.32	0.5929	165.7
8	24.06	0.7833	374.1
16	38.38	0.6640	234.5
36	21.96	0.7776	409.8

** 90% Reduction (10 ug/L to 1 ug/L) dose calculated*

After: Huck and Andrews (1988)

Table II:Freundlich Isotherm Constants for Chloroform At Various Pre-loading Times

background organics in the liquid phase reduce the number of active sites available in the adsorbent.

Kinetic effects are important in determining the efficiency of adsorption in practice. In column adsorbers, they are a major factor leading to earlier breakthrough than predicted from equilibrium considerations (Figure 1).

3.6 Powdered versus Granular Activated Carbon

The primary differentiation between PAC and GAC is its particle size. The PAC particle size distribution is such that at least 80% of the carbon should pass No. 325 mesh, or measure less than 44 um. GAC, on the other hand, will have a particle size larger than about 0.2 to 0.3 mm. The application of the two activated carbon forms in treatment of drinking water also varies. GAC is used in columnar flow schemes (plug flow reactors - PFR) where water is percolated through the GAC bed. PAC is dispersed in water prior to sedimentation and/or filtration (continuous stirred tank reactors - CSTR).

In a PFR, the concentration of the adsorbate decreases progressively through the system, while in a CSTR the concentration drops immediately to a low value. This is well illustrated in Figure 2. As a result of this fact, a PFR (carbon column bed arrangement) is more efficient than a CSTR (clarifier) because the loading on the adsorbent increases with increase in adsorbate concentration i.e. equilibrium conditions.

Percolation through an activated carbon bed therefore offers great possibility for effective operating conditions. While PAC with its smaller particle size offers a larger surface availability and therefore

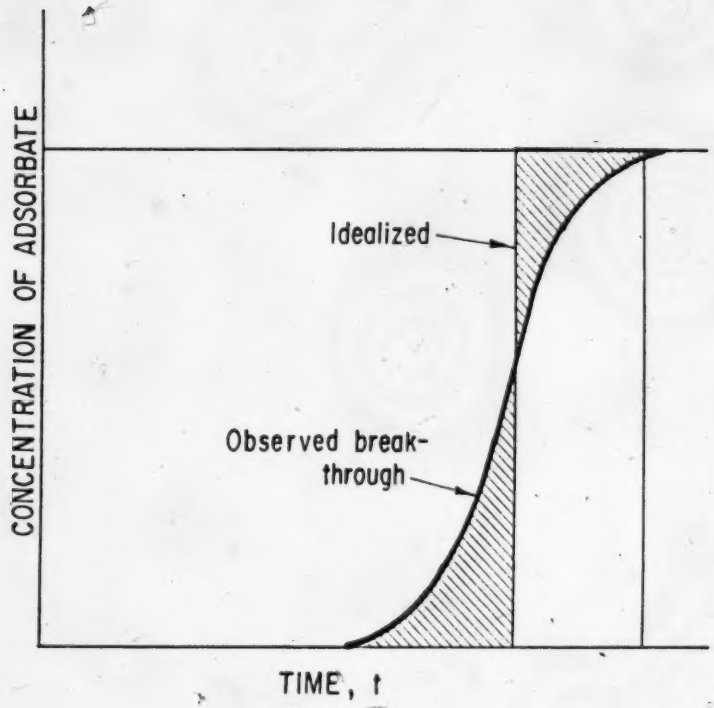
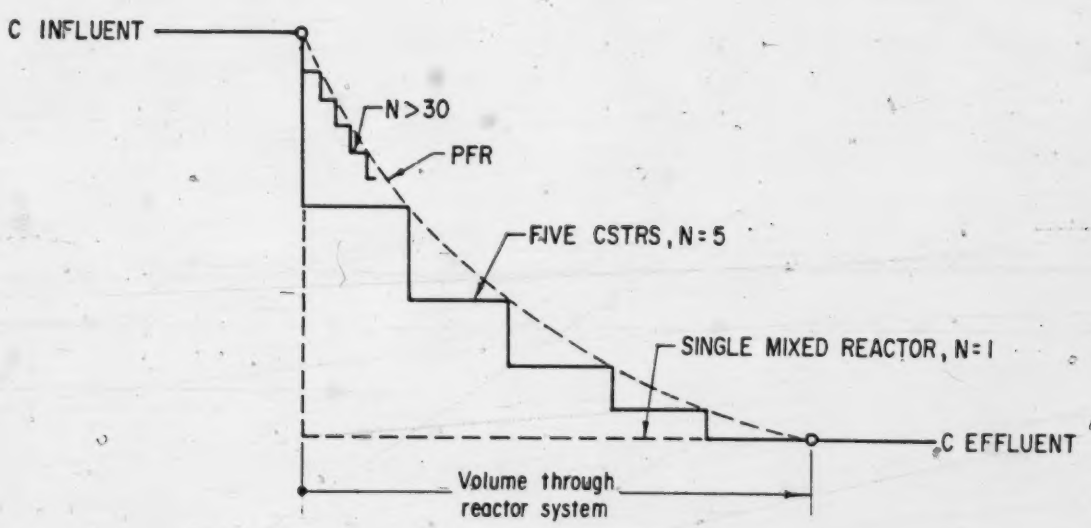


Figure 1: Breakthrough Curves Through A Column Adsorber



AFTER LEVENSPIEL (1972)

Figure 2: Concentration Profile Through Reactor Systems

would be more efficient and economical than GAC, it is unsuitable for use in columnar flow schemes.

In drinking water treatment, PAC addition involves minimal additional capital cost, and is therefore often cheaper overall than GAC. However, the effective use of PAC is hindered by dosage restrictions, and in some cases short-term contact with water. Therefore the full capacity of PAC is never utilized and its application becomes uneconomical.

PAC application, by virtue of its low capital investment and the ability to change the PAC dose as the water quality changes, is still adaptable to systems with periodic or seasonal problems or where low contaminant levels require less carbon. In continuous application of activated carbon, the powdered form may become costly. However, research may show methods to optimize PAC usage through alternative applications.

3.7 PAC Special Applications

Traditionally, PAC use in drinking water treatment plants has been limited to taste and odour control, and typical dosages for this use range from 5 to 20 mg/L (AWWA Committee Report, 1977). PAC is seldom applied on a continuous basis, and therefore in the past, there has been little incentive to optimize its use. Research into improving PAC application procedures is now receiving serious consideration. Two new applications that promise to significantly improve the use of PAC are:

(i) The Roberts Haberer Process:

The Roberts-Haberer process was first developed by

Dr. Klaus Haberer in Wiesbaben, West Germany and later modified by the Roberts Filter Manufacturing Company (Hoehn, 1984).

In this process PAC is coated onto an upflow filter media composed of buoyant polystyrene spheres 1 to 3 mm in diameter. On saturation, the PAC is removed from the beds by backwashing the media (downflow) with a high flow rate. New PAC is then applied to the beds. The advantages of the system include: high PAC utilization rates, PAC is used as required, biological growths and desorption are minimized, low carbon inventory and the ability to recover PAC for regeneration if desired. The disadvantages are the escape of PAC from the beds requiring removal in subsequent steps and the requirement for intermittent dosing and backwashing. Results by Hoehn (1984), showed that only 160 bed volumes of the raw water was treated before replacement of PAC was necessary.

(ii) Fluidized-bed PAC Adsorbers:

As discussed earlier, conventionally applied PAC remains in the water for only a short period of time, and precipitation of metal hydroxides may retard adsorption kinetics (Carns and Stintson, 1978). The addition of PAC to floc blanket clarifiers has the advantage of long residence time in the blanket and there is good contact between the floc and water flowing through, enabling equilibrium to be approached. The main advantage of this application is that no major treatment modifications are required, and PAC can also act as nuclei in

low turbidity water for improving flocculation. Studies have indicated tangible benefits of this application. Snoeyink (1986) cites that PAC dose for detergent removal in a fluidized bed could be reduced by 25 to 40% in comparison to use of carbon in conventional systems. Hoehn (1987) observed that concentrations attained in the floc blanket are far greater than can be expected when PAC is used in conventional treatment.

3.8 Summary and Research Needs

The discovery of numerous organic chemicals in public water supplies and health related concerns due to the presence of these chemicals has brought the entire subject of their effective removal to the forefront. Public suspicion has prompted regulatory agencies throughout North America to introduce stringent regulatory and monitoring standards for various organic chemicals in drinking water supplies. The underlying sense of urgency to meet the new standards is the most problematic aspect faced by industry professionals. Research efforts are underway to find cost effective means to remove organic contaminants in an attempt to meet the new standards.

Among the processes considered is carbon adsorption. In North America, PAC is widely being used to control taste and odour problems. While some measurements of its organic removal capabilities have been made, PAC has received far less attention than GAC. In many instances where low levels of organic contaminants are to be removed or where only seasonal problems with organics in water supplies exist, optimal PAC application could help meet the removal requirements without

the large capital investment that would be required for alternate treatment methods such as GAC or ozone.

One such method of treatment using PAC in a cost effective manner that needs to be researched is the solids contact clarifier providing internal slurry recirculation. The slurry recirculating solids contact clarifier, like the fluidized bed reactor, enables the retention of considerable quantities of PAC. Also the sludge wasting rate can be adjusted to optimize the overall residence time of the floc in clarifier. The recirculating slurry (usually four or five times the volume of the incoming water) also enhances the contact periods between the floc and the incoming water. In wastewater treatment studies (Beebe, 1973 and Galland, 1970) on PAC use in a slurry recirculating solids contact clarifier have shown 30-40% greater carbon efficiency in the removal of Total Organic Carbon (TOC) and Chemical Oxygen Demand (COD) in comparison to conventional type clarifiers.

While much of the research in the area of PAC use in solids contact type clarifiers discusses improved efficiency and performance of PAC, the literature indicates that a comprehensive evaluation to: (i) quantify the accumulation of PAC; (ii) realize the PAC distribution profile; and, (iii) evaluate adsorption performance of PAC slurry; has not been carried out for a solids contact clarifier.

A need for such a study greatly exists, to form a basis for further studies on the application of PAC to attain removal of specific organic contaminants.

CHAPTER 4: PILOT PLANT COMMISSIONING AND OPERATION

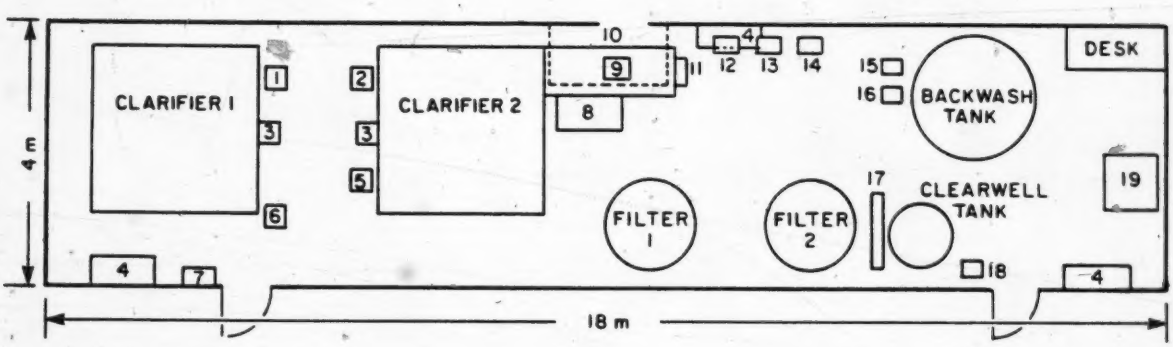
4.1 Pilot Plant Process Schematic

The pilot plant used to carry out this research was mounted in a mobile trailer. Details of the plant are provided in Appendix III. Figure 3 shows a sketch of the plant layout and Figure 4 provides the process schematic. The main components of the pilot plant used for this investigation were the two clarifiers. A detailed cross-section of the solids contact slurry internal recirculating slurry (SCSRC) pilot clarifier is shown in Figure 5. Table III summarizes the operating specifications of the clarifiers. The SCSRC operates on the principle of providing a solids contact mixing (rapid and slow) zones and embodies an internal slurry recirculation which enables about four or five times the volume of incoming water to recirculate through the rapid mix zone. The clarifier combines the advantages of a rapid and slow mixing sludge recirculation for enhanced contact, and sludge contact settling.

For the purpose of this research, the filter component of the plant was only used as a flow-through holding tank. The operation was limited to the use of the two clarifiers in parallel mode as shown in Figure 6.

4.2 Pilot Plant Commissioning and Operation

Prior to the commencement of this experiment, several modifications and commissioning activities had to be carried out. These activities occupied a substantial fraction (35%) of the total research period. The pilot plant had never previously been operated in its entirety. In particular, the clarifiers had never before been used for the process of clarification.



LEGEND

1. ALUM FEED
2. LIME FEED
3. RAPID MIX CHAMBERS
4. HEATERS
5. CARBON FEED
6. POLYMER FEED
7. CHLORINE DIOXIDE SYSTEM
8. CONTROL PANEL
9. AIR BLOWER
10. CHLORINE ROOM
11. TURBIDIMETER
12. TOTAL CHLORINE ANALYZER
13. HARDNESS ANALYZER
14. FREE CHLORINE ANALYZER
15. BACKWASH PUMP
16. UTILITY PUMP
17. POTABLE WATER METERING PROBES (pH, conductivity, temperature, photometric analyzer)
18. TRANSFER PUMP
19. COMPUTER CONTROL SYSTEM

Figure 3: Layout Of Mobile Pilot Water Treatment Plant

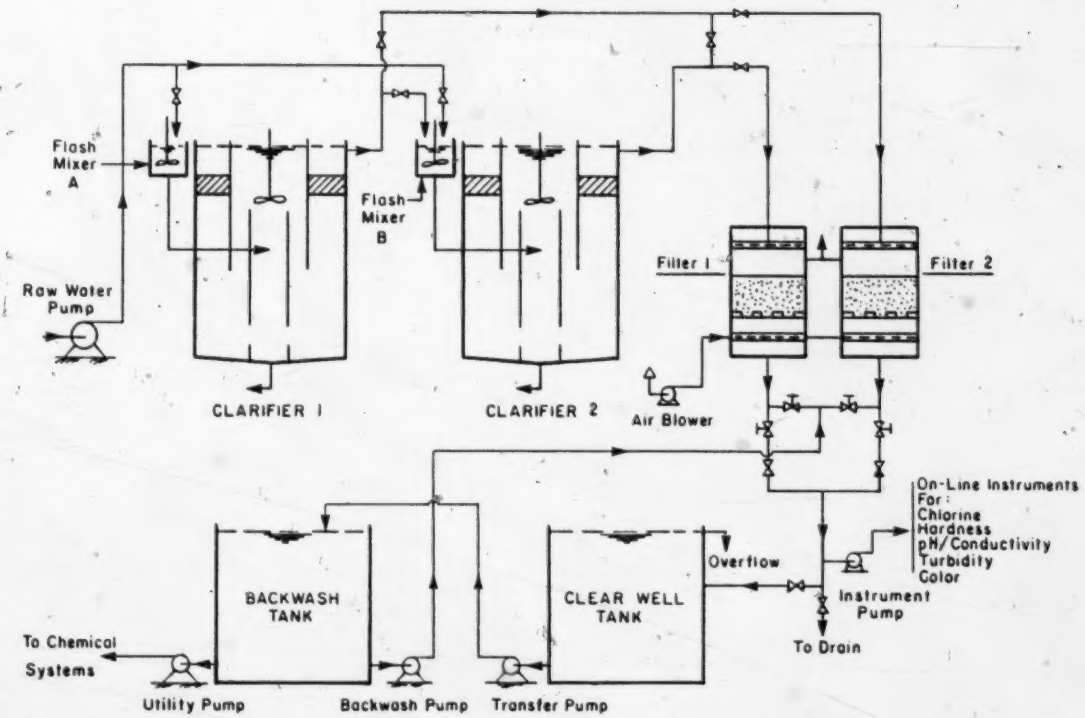
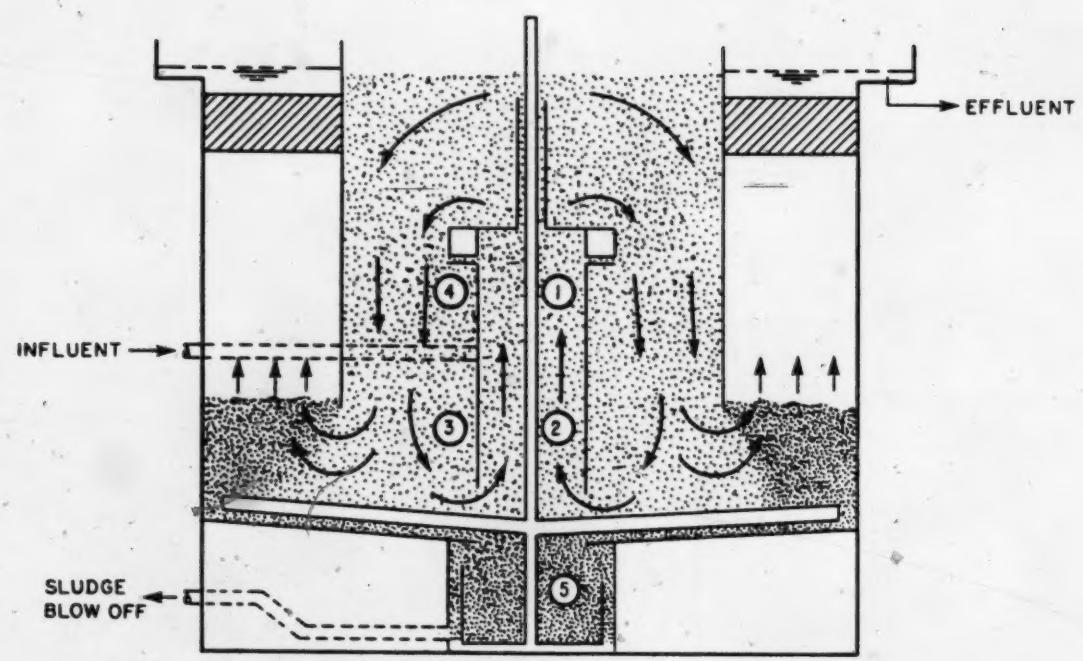


Figure 4: Mobile (Pilot) Water Treatment Plant - Process Schematic



LEGEND:

(#) – SLURRY SAMPLING POINTS

Figure 5: Pilot Clarifier - Cross Section

THROUGH FLOW L/min	RISE RATES m/hr	RETENTION TIME min
50	1.3	194
100	2.6	97
150	3.9	65
200	5.2	49

Table III: Pilot Clarifier Operating Specifications

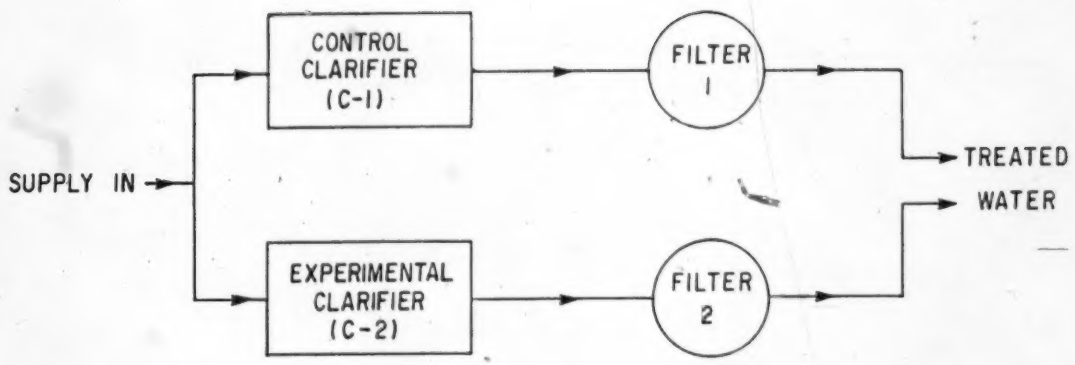


Figure 6: Pilot Plant - Parallel Flow Arrangement

Information on their operating requirements was therefore necessary and had to be obtained through first hand experience.

4.2.1 Clarifier Design

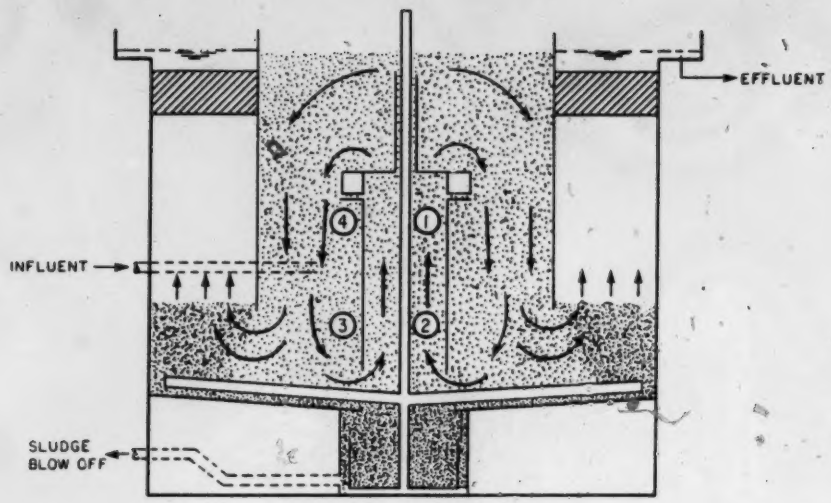
An examination of the existing clarifiers with respect to their construction and requirements for meeting the experimental needs necessitated the following three activities.

4.2.1.1 Inlet Pipe

A physical inspection of the clarifier revealed a major flaw in the construction of the inlet raw water pipe entering the clarifier. As shown in Figure 7(A), the inlet pipe did not extend to the center draft column of the clarifier as would be the case in a typical solids contact internal recirculating slurry clarifier. Figure 7(B) shows the correct pipe entry into the clarifier and modifications to correct this were carried out.

4.2.1.2 Sample Points

For the purpose of this study, to quantify the carbon accumulation, and also to enable the proper operation of the solids contact internal recirculating clarifiers, the constant monitoring of solids in the center section (see dotted area in Figure 5) must be carried out on a regular basis. The clarifiers did not provide for any means to obtain these samples. Four sample points (1 - 4) as shown in Figure 5 were therefore installed in both clarifiers. The location of these sampling points were selected to resemble sampling points in the large scale E.L. Smith clarifiers.



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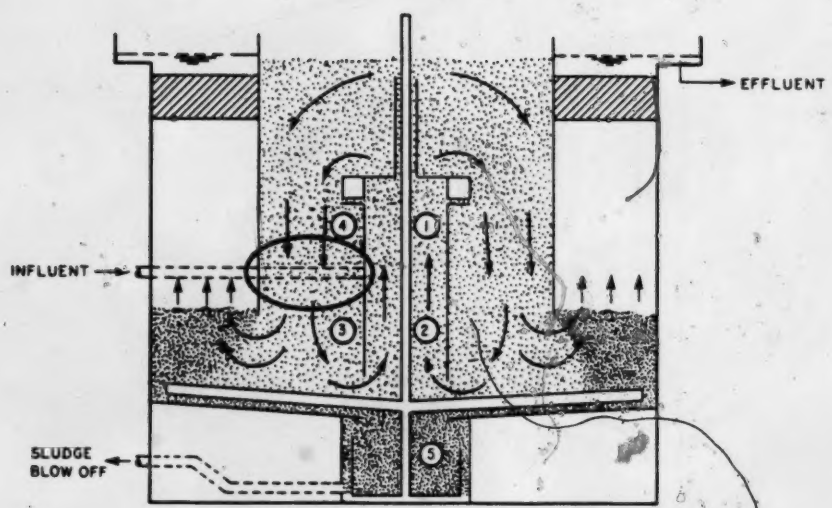


Ⓑ - AFTER

Figure 7: Pilot Clarifier - Inlet Pipe Modifications

4.2.1.3 Rapid Mixing

Usually in a water treatment process, the clarification process consists of the following components: (i) chemical addition, (ii) rapid mix, (iii) flocculation, and (iv) sedimentation. The full scale E.L. Smith Facility includes all of the above components. In the pilot facility, while provisions existed for rapid mixers, these mixers were not in place. High speed mixers were ordered and installed to satisfy this requirement and keep the process in line with the full scale plant.

4.2.2 Plant Hook-up and Preparation

The mobile pilot facility was located at the E.L. Smith Plant to run in parallel with the large scale process and subjected to the same raw water source. The exact site location was selected on the basis of its accessibility to all the utilities required in the operation of the pilot plant without causing any interference to the large scale facility operation.

4.2.2.1 Raw Water Source

The raw water to the pilot facility had to be drawn from the full scale plant's 1.83 m (72") diameter raw water feed line, prior to the addition of any chemicals. To avoid any major costs of tapping in a new line for the pilot plant, an existing carbon feed line was relocated at a minor cost. Initially, the raw water piping was connected to the pilot facility directly from the large scale raw water pipe, but, a flow test revealed that the pressure in the large pipe

failed to provide adequate flow to the pilot plant. An additional pump was installed to boost the flow to the pilot plant.

4.2.2.2 Power Source

The pilot facility had a power requirement of 220 Volts while the large scale plant operated at a 600 Volt power source. A transformer to lower the power voltage was rented for the duration of the study.

4.2.2.3 Winterizing

Due to the extreme weather conditions (as low as -40°C) to be experienced through the course of this experiment, proper winterizing of the pilot plant trailer was required. The lower end of the trailer was boarded up with a 2x4, fibre glass insulation, and plywood construction. Temperature sensors were installed to enable monitoring of the trailer temperature in the lower boarded section. Shortly into the winter months, heaters were installed after very low temperatures were noted and the possibility of freezing increased. Inspite of all the precautions an operator error, just prior to the commencement of experimental runs resulted in one of the trailer entrance doors being left open, which caused the freezing and rupture of various pipes and a sludge pump inside the trailer. Major repairs were necessary resulting in the delay of this study.

4.2.3 Plant Start-Up

Once all the hook-ups and winterizing protection were in place, the plant start-up activities commenced.

4.2.3.1 Solids Slurry

The basis of solids contact slurry recirculating clarifier operation, as the name suggests, is the formation of the solids slurry. It is only after a good concentration of solids slurry is formed that effective clarifier performance is accomplished. Usually during start-up the initial solids slurry is formed by incoming suspended solids. However, when the incoming suspended solids concentration is not high enough, an initial solids seeding of the clarifier is necessary if immediate clarification performance is to be expected. In the case of this study, the winter condition raw water conditions did not provide adequate suspended matter concentration (the turbidity was < 10 N.T.U.) to enable quick start-ups. The seeding of the clarifier was therefore necessary.

In the main plant the seeding of clarifiers is usually carried out by recycling waste calcium carbonate sludge, a by-product of the softening process. Due to the presence of PAC in the large scale plant sludge, its use for pilot plant seeding was not possible. Alternative means for seeding the clarifier were therefore sought. At first, bentonite clay was used for seeding and appeared to work. However over a period of 4 to 5 days of continuous operation, the slurry would dilute and disappear through the clarifier effluent. This was experienced on three separate occasions and usually the bentonite solids slurry would diminish overnight.

Alternative clarifier seeding methods were investigated and after several unsuccessful attempts one "recipe" finally worked. The method for seeding is outlined in Chapter 5. The method was tested twice

after its initial success to confirm its reliability during an experimental run.

4.2.3.2 Coagulant Selection

The performance of the clarifier process is based on its particulate removal efficiency. Usually the turbidity of the outgoing treated water from the clarifier is a good indicator of the clarifier's performance.

To attain efficient removal, chemical coagulants are added just prior to the clarification process. This alters the surface properties of particulate material present in the incoming water and causes aggregation of small particles into large units, or precipitates ("flocs") for which separation by sedimentation is feasible.

In the pilot facility, initially the coagulants selected were those used in the large scale E.L. Smith facility, i.e. aluminum sulphate and an anionic polymer. The operation of the pilot clarification process however did not perform as efficiently as the large scale plant. High (>10 NTU effluent) turbidities were experienced. During the time that the pilot plant was being commissioned, the large scale E.L. Smith Plant was carrying out an alternative coagulant study of Aluminex^R (Polyaluminum chloride). Due to the problems experienced with aluminum sulphate at the pilot plant, Aluminex^R was tried as an alternative and clarifier efficiencies improved substantially. As shown in Figure 8, effluent turbidities using Aluminex^R and LT27 polymer were superior to those with aluminum sulphate and LT27 polymer. Aluminex^R and

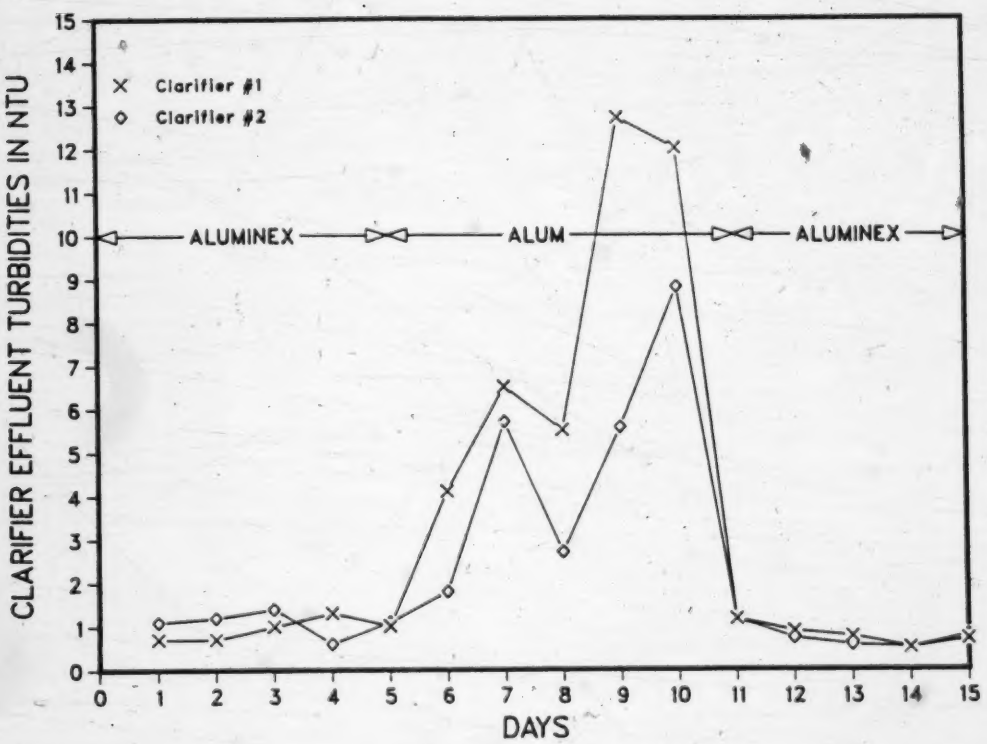


Figure 8: Coagulants - Effect On Clarifier Performance

Percol LT27^{R} polymer were therefore selected as the coagulants for the pilot plant.

4.2.3.3 Carbon Feed System

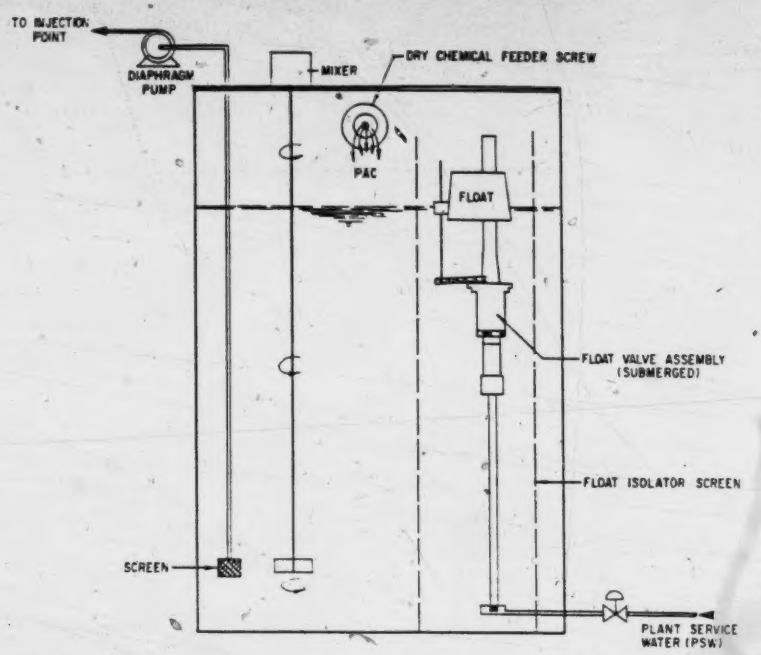
After the clarifiers were operational, preparations for experimental runs were made. The commissioning of the existing PAC feed equipment, an important requirement for the study, met with some problems.

Figures 9(A) and (B) show the modifications made to improve the reliability of the carbon feed system. Initially the existing float system (submerged type) in the carbon slurry tank would repeatedly stick due to carbon deposits, causing overflow of the tank. The submerged system was replaced with an improved float system and the problem did not recur.

The second problem encountered with the carbon system was the diaphragm slurry feed pumps which would intermittently plug up due to PAC build up. These pumps were replaced successfully by Little Giant^{R} centrifugal pumps. The only problem with the Little Giant^{R} pumps were that they would wear out after approximately 300 hours runtime and had to be replaced. To ensure reliability during experiments, a back-up system with easy switch over capability was also installed.

Finally, the feed lines were observed to experience a slow build up of carbon on the inside of the pipe. A solenoid valve with timer control was installed to provide flushing of the line with high pressure water at regular intervals (30 min).

A. PAC MIXING TANK BEFORE MODIFICATIONS



B. PAC MIXING TANK AFTER MODIFICATIONS

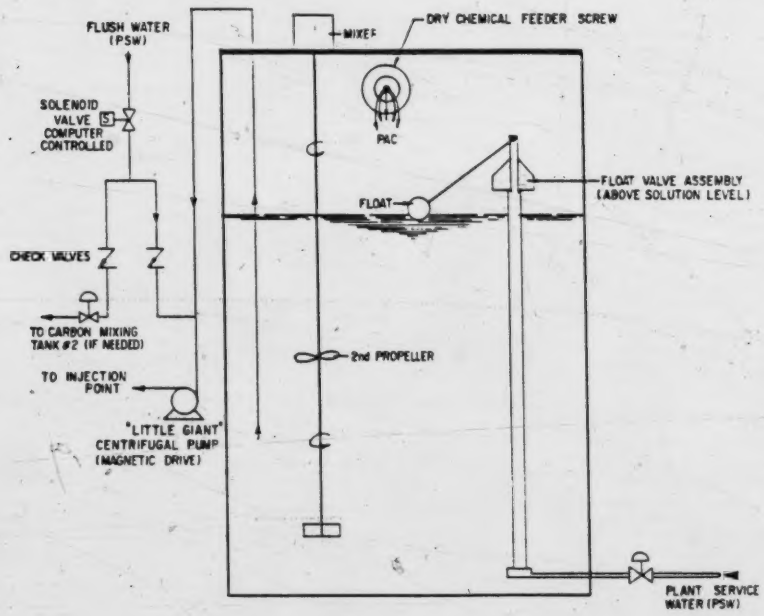


Figure 9: Pilot Plant - Carbon System Modifications

The PAC system (after all of the above modifications) operated reliably throughout the experiment.

4.2.4 Performance Comparisons

Before the experimental runs could commence, two important aspects of the pilot plant operations had to be established. The first was the comparison in operation of the two pilot clarifiers. Since the basis of the experimental runs was to compare performance of carbon added to one clarifer, while the other was used as a control (no carbon feed) it was imperative that the two clarifiers behaved similarly when subjected to the same conditions. The second comparison was to ensure that the pilot scale clarifiers operating performance was similar to the full scale, E.L. Smith clarifier, performance.

4.2.4.1 Tracer Studies

To confirm the similarity in the two pilot plant clarifiers, tracer studies were carried out to characterize their dynamic behavior.

Two separate tracer techniques were used:

(i) A step input dose in which strontium chloride (selected inert tracer) was introduced in the clarifier influent at a constant rate for a 3 hour period and the response observed in the effluent. Figure 10 shows the response observed from the 2 clarifiers.

(ii) A pulse input dose in which a large amount of strontium chloride was injected ("quickly dumped") in the influent and the response of the two clarifier effluents were

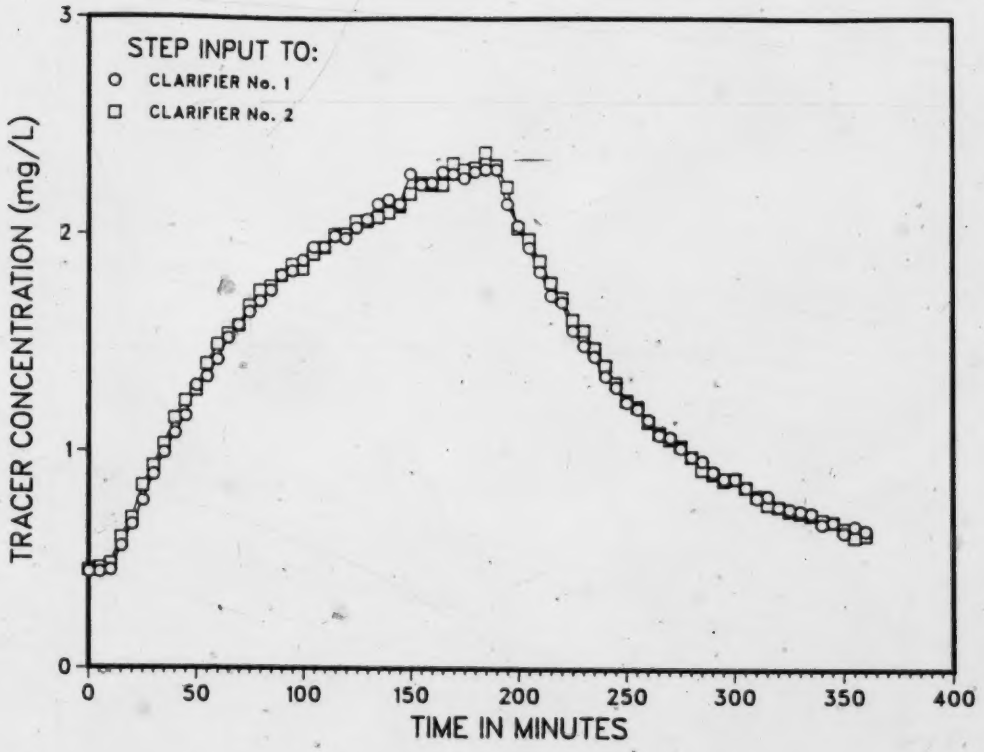


Figure 10: Response Curve In Clarifiers To Tracer Step Input

observed. Figure 11 shows the response observed from the pulse input.

To confirm the graphical similarity in response behavior indicated by the two Figures (10 & 11), a mathematical analysis of average residence time using the Danckwerts model (Hill, 1977) was carried out (see sample calculations in Appendix I). The results are summarized in Table IV. A retention time varying between 63 and 67 min for both clarifiers at 150 L/min flow was obtained by the two different tracer techniques. This exercise confirmed the similarity in hydraulic character of the two clarifiers.

4.2.4.2 E.L. Smith vs. Pilot Plant

Throughout the commissioning phase of the pilot plant, the aim was to achieve comparable results to the full scale E.L. Smith Plant. Initially, before the selection of Aluminex^R as a coagulant for the pilot plant, the matching performance was difficult to attain. After the selection of Aluminex^R, the performance of the pilot plant improved substantially and its optimum operational performance came within 10% of the full scale plant. Table V summarizes the comparative operational data for the two plants.

4.3 Pilot Plant Process Routine Operation

Table VI best illustrates the activities involved in the daily operation of the pilot plant. The main activities can be grouped into four:

(i) Incoming Flow Monitoring - involved recording the flow meter readings and adjusting the valves or pumps if necessary;

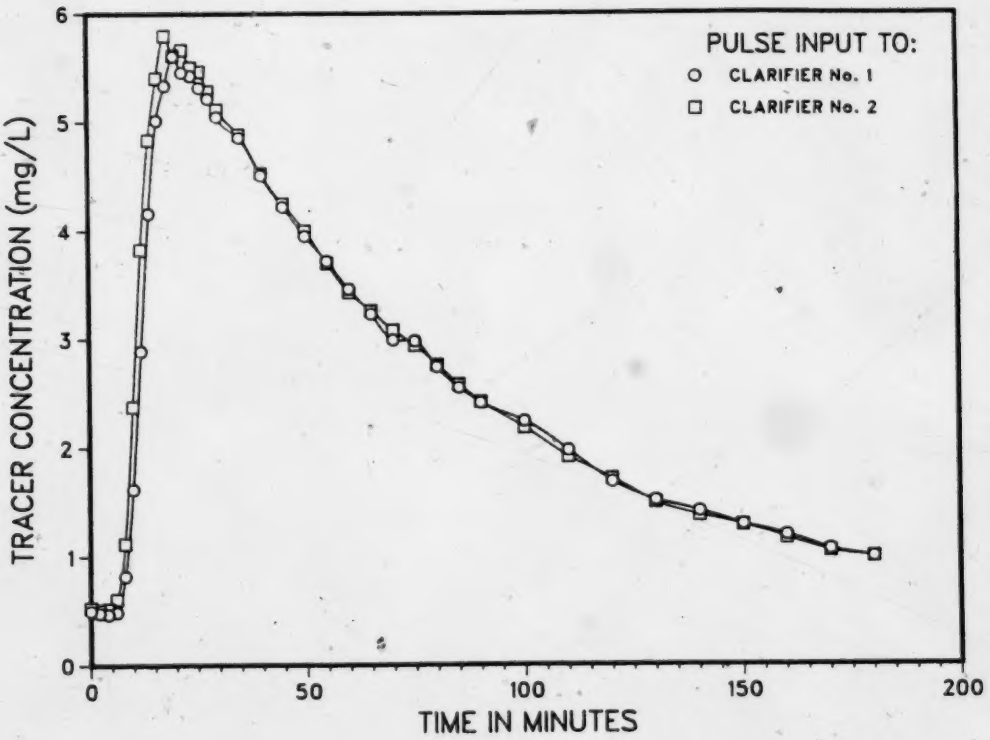


Figure 11: Response Curve In Clarifiers To Tracer Pulse Input

DESCRIPTION	*CLARIFIER 1*	*CLARIFIER 2*
Flow Rate	150 L/min	150 L/min
Theoretical Residence Time	65 min	65 min
Calculated Residence Time:		
Step Input Tracer	67 min	65 min
Pulse Input Tracer	65 min	63 min

Table IV: Summary of Clarifier Residence Times

DESCRIPTION	PILOT PLANT	E.L. SMITH PLANT
PEAK DESIGN DATA		
Flow	205 L/min	200 MLD
Clarifier Rise Rates	5.3 m/hr	5.6 m/hr
Residence Times		
Clarifier	47 min	86.4 min
Solids Contact Chamber	14 min	18.2 min
Rapid Mixer	15 sec	0.04 sec
Volumes		
Total	9.7 m3	12,488 m3
Draft Tube	0.08m3	118 m3
Inner Mix Zone	2.85 m3	2525 m3
Rapid Mix	0.05 m3	5 m3
COMPARATIVE PERFORMANCE DATA		
(@ Effluent Turbidity < 2.0 N.T.U.; Water Temperature = 0.5°C)		
Flow	150 L/min	150 MLD
% of Peak Design Flow	73 %	75 %
Retention Times	64 min	115 min
Rise Rates	3.9 m/hr	4.2 m/hr

Table V: Comparison Of Operating Data -Pilot Plant vs E.L. Smith Plant

Table VI: Pilot Plant Daily Operation Log Sheet

PAC RESEARCH PROJECT LOG SHEET

DATE & TIME		RAW FLOW		QUALITY PARAMETERS				CLARIFIER V/Vo (%)					BLOWDOWN		RECIRC SPEED	RAPID MIXER SPEED	CHEMICAL INJECTION								COMMENTS
																	ALUMINEX		ALUM (dry)		PERCOL LT27		CARBON (PAC)		
		% of 300 LPM	LPM (l/min)	TURB NTU	pH	COLOR TCU	UV mg/L	1	2	3	4	5	(min)	(litre)	(RPM)	(RPM)	mL/min	mg/L	g/min	mg/L	mL/min	mg/L	g/min	mg/L	
	C1																								
	C2																								
init ____	RAW							RAW WATER TEMP =																	
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	C2																								
init ____	RAW							RAW WATER TEMP =																	

(ii) Clarifier Monitoring and Operation - monitoring of solids in center (4 sample points), effluent quality and mixer speeds. On the basis of the monitoring results, make operational changes,

i.e. draining, mixer speed adjustment and chemical dosage changes;

(iii) Chemical Feed Systems - confirm feeds through pump calibration checks, replenish tank inventories;

(iv) Meter Checks - calibrate on line instruments and ensure accuracy of readings.

During experimental runs, slurry samples were collected from the five sample points as per the experimental design requirements.

Maintenance on equipment was carried out on an ad-hoc basis. Most of the maintenance activities were carried out between experimental runs and included clarifier washout, pump replacement and checks, sample lines flushing, etc.

CHAPTER 5 : METHODS AND MATERIALS

5.1 Methods for Laboratory Analysis

5.1.1 Carbon in Clarifier Solids Slurry

One of the most challenging aspect of this study was the development of a method to analyse the concentration of carbon in the aluminum hydroxide based clarifier solids slurry. An extensive literature review did not disclose a method to analyse the amount of carbon in the slurry.

5.1.1.1 Basis for Method Development

A typical clarifier slurry for raw water treatment consists of: (i) aluminum hydroxide (coagulant); (ii) polymer (organic coagulant aid); (iii) other inorganics; (iv) adsorbed or retained organics; and (v) PAC.

The critical measurement in quantifying the presence of carbon is its weight, and therefore a gravimetric analysis approach (Jenkins et. al., 1980) was considered appropriate. On the basis of the main constituents outlined above, the following analytical steps were considered:

(i) Acid Dissolution: Acid dissolution was considered the most effective method to separate the carbon from the aluminum hydroxide precipitate. The aluminum hydroxide precipitate dissolves into solution at low pH.

(ii) Filtration: Once the aluminum hydroxide is dissolved, the remaining suspended mass including PAC, can be separated from the solution phase by filtration.

(iii) Volatilization: Subjecting the filtered suspended mass to volatilization will remove any remaining water and low boiling point (volatile) organics.

(iv) Combustion: The final combustion procedure will convert a large part of the PAC into CO_2 and enable quantification of PAC from inorganic matter remaining in the suspended mass after volatilization.

Figure 12 provides a pictorial representation of the effects the above procedures would have on the solids slurry sample.

5.1.1.2 Method Concerns and Solutions

Before the method could be developed, each of the main constituents of the solids slurry were individually subjected to the four steps (acid dissolution, filtration, volatilization and combustion). The results of this exercise are summarized in Table VII.

Note that calcium carbonate was also incorporated in this analysis because of its presence in the clarifier slurry (introduced during seeding). These results lead to the following observations:

(i) Aluminum Hydroxide (Aluminex^R) and Calcium Carbonate: The analysis showed that almost all of the aluminum hydroxide (>99%) is dissolved in the acid dissolution stage and 94% of the calcium carbonate is also dissolved. No further loss is experienced to either of these constituents during the combustion stage.

(ii) Polymer: About 74% of the polymer appears to have been

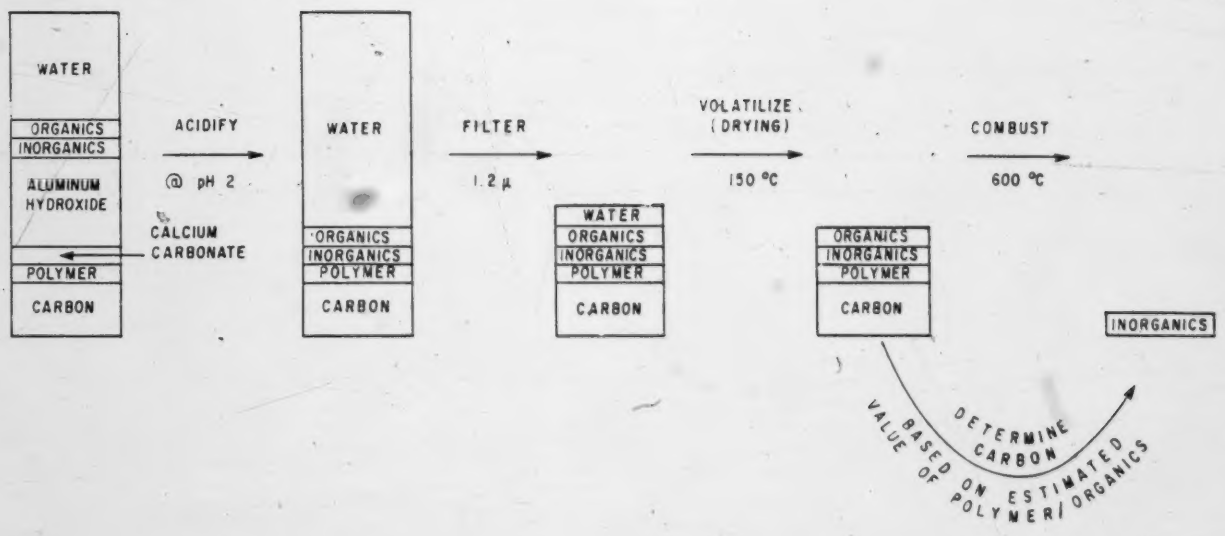


Figure 12: Pictorial Representation Of Carbon Determination Analysis

CONSTITUENT	INITIAL CONCENTRATION	ACID WASH/DRYING		COMBUSTION	
	mg/100mL	mg Retained	% Total	mg Combusted	% Total
Polymer	1.62	1.2	74	0.7	58
Aluminex TM	431	1.8	0.4	0	0
Calcium Carbonate	88	5.5	6	0	0
Carbon (PAC)	290	264	91	256	97

Values reported are average of 3 replicates

Table VII: Effect Of Carbon Analysis Steps On Individual Slurry Constituents

retained after the acid dissolution filtration and volatilization stage. A further 58% loss occurs in the combustion stage.

(iii) Carbon: About 91% of the carbon is retained after the volatilization (drying) procedure and 97% of that remaining was lost in the combustion stage.

On the basis of the above observation, a method for determining the carbon concentration was successfully developed. Known amounts of all of the above constituents to simulate clarifier slurry conditions were mixed and subjected to the procedure. PAC concentration results derived from the method are summarized in Table VIII. The results are within 10 percent of actual amounts. During experimental runs, a correction factor to account for errors caused by the presence of polymer was determined by using the control clarifier slurry results. However, it was later realised that the polymer content of the slurry did not change during the course of the experiment. Therefore the polymer content derived just prior to the PAC addition was used for correction through the experimental run. This is covered in section 5.1.1.3 (f)

5.1.1.3 Method

(i) Apparatus:

-Analytical balance, to 0.001 g or better.

-Glass fibre filters, GF/C or equivalent (90 mm circles or as required to fit Buchner funnels).

-Laboratory oven capable of 150°C.

-Muffle furnace capable of 600°C.

SAMPLE NO	ACTUAL AMOUNT ADDED mg/L	MEASURED VALUE mg/L	% DIFFERENCE
1	38	39	4
2	71	67	6
3	107	104	3
4	204	198	3
5	409	398	3
6	807	852	6
7	1738	1608	7
8	3306	3298	0.25

Values Reported are average of 3 replicates

Table VIII: Comparisons Of PAC Concentrations - Actual vs Measured

-Muffle furnace tongs

-Dessicator sufficiently large to hold four or more glass fibre filters in petri dishes or similar containers.

-Crucibles.

-Petri dishes.

-Tweezers.

-Vacuum pump (filtering flasks).

-Measuring cylinder.

-250 mL beakers.

(ii) Reagents:

-Distilled water or equivalent.

-Sulphuric acid, 9% w/w.

(iii) Procedure:

a) Filter Preparation (tweezers were used at all times when handling filters)

-Dried filters in petri dishes overnight at 105°C.

-Placed the dried filters, in petri dish, into the dessicator until cool (about 10 minutes).

-Weighed filters* only to four decimal places. This was the tare weight.

*Filters required were 3 replicates per sample plus two blanks.

b) Acid Dissolution

- Using a measuring cylinder measured 3 x 100 mL of slurry

sample and poured into a 250 mL beaker (3 replicates each). Also prepared 100 mL distilled water for 2 blank replicates for each round of analysis.

- Poured 10 mL of 9% w/w sulphuric acid solution into the beaker contents. Mixed the contents thoroughly and allowed to stand for 3 to 5 minutes.

c) Filtration

- Filtered each sample using Buchner funnel and vacuum flask, employing a previously tared glass fibre filter. Excercised caution during the filtration to ensure that all the solids were trapped on the filter, and none was stuck to the sides of the funnel. Washed down visible solids remaining in the beaker with small quantities of water.

d) Volatilization (Drying)

- Placed filters in petri dishes and dried at 150°C for one hour or more.
- Then placed in dessicator until cool (10 minutes or so).
- Weighed filter and retentate. This weight was the initial retentate plus filter weight.

e) Combustion

- Preheated muffle furnace to 600°C (Approximate - not calibrated).
- Folded the filters and placed them into the crucibles.
- Placed crucibles into the muffle furnace for one hour.

- Removed from muffle furnace and placed on a heat resistant surface (brick in this case) for 5 minutes.
- Placed in dessicator until cool (15 minutes).
- Weighed the filter plus ash. This gave the final weight.

f) Calculation

Figure 13 is a visual aid to assist in understanding the calculations below:

Ci = undried PAC (initial) weight, g.

Cf = PAC weight acid washed, filtered and dried, g.

Cc = combusted PAC weight, g.

Si = sludge (initial) weight, g.

Sf = sludge weight acid washed, filtered and dried, g.

Sc = combusted sludge weight, g.

Ts = total solids weight (initial), g.

Ds = total dried solids weight, g.

WL = total weight loss due to combustion, g.

Fc = filter weight loss due to combustion, g.

Kc = fraction of combusted PAC

Ks = fraction of combusted sludge

Assume: Cf = Ci (no PAC loss during acid wash and drying)

$Ds = Cf + Sf = Ci + Sf$ .....(1)

$WL = Cc + Sc + Fc$.....(2)

$Kc = Cc/Cf = Cc/Ci$.....(3)

$Ks = Sc/Sf$.....(4)

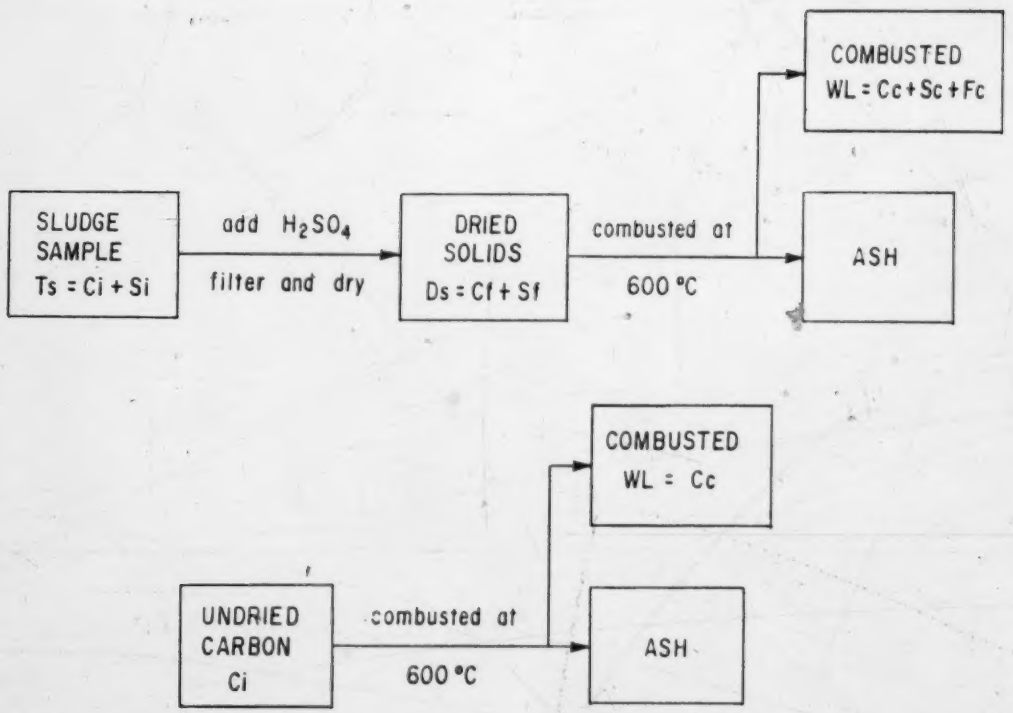


Figure 13: Box Diagram To Illustrate PAC Determination In Slurry Samples

Solving for Ci: $Ci = \frac{(WL - Fc) - KsDs}{Kc - Ks}$

Typical values for: Kc = 0.898; Ks = 0.143; Fc = 0.0029 g.

5.1.2 Carbon Isotherms

The bottle point method was used to derive a reference isotherm using Transpacific PAC and raw river water obtained at the E.L. Smith Plant. To determine the isotherms on clarifier slurry a "modified" bottle point method was used. Both these methods are described below:

5.1.2.1 Bottle Point Method

(i) Sample Bottle Preparation:

- Obtained 24 acid washed 160 mL serum bottles, rubber caps and Teflon^R liners.
- Labelled bottles for subsequent identification.
- Weighed appropriate amount of powdered activated carbon ranging from 2 mg to 350 mg, corresponding to dosages from 12.5 mg/L to 3000 mg/L.
- Capped bottle with aluminum foil and stored.

(ii) Sample Solution Preparation:

- A 12 L stainless steel delivery tube, Teflon^R cap and Teflon^R stir bar were washed and where possible baked before the experiment began.
- The delivery tube and accessories were assembled in preparation of the experiment.

- The delivery tube was then filled with 1.5 times the required amount of river water from the E.L. Smith Plant
- A Teflon^R stir bar was placed into the delivery tube.
- 1.0 M KH_2PO_4 buffer solution was added at a ratio of 1 mL KH_2PO_4:2 L water.
- The Teflon^R cap was then carefully placed on top of the water solution in the delivery tube, ensuring that no water seeped into the cavity on top of the cap.
- A glass gas tight syringe was first rinsed with methanol and then with a solution of chloroform in methanol.
- The desired amount of chloroform was then injected into the delivery tube, using this syringe and approximately 30 minutes were allowed for the solution to mix thoroughly.

(iii) Bottle Filling and Equilibration:

- The 160 mL bottles prepared in part (i) were then filled. The first 2 bottles and every third bottle after that were blanks containing no carbon. The bottles were filled headspace free, covered with Teflon^R liners immediately and sealed with rubber/aluminum caps. The bottles were then placed in a rotary tumbler (equilibrator) operated at 25 RPM to facilitate mixing. The bottles and contents were subjected to an equilibration period of 7 $\pm$ 0.5 days. The entire equilibration procedure was carried out in a temperature controlled room at 20 $\pm$ 1^{o}C to simulate actual treatment process conditions.

(iv) Sample Extraction and Storage:

- The bottles were removed from the equilibrator after 7 days.
- The bottles were then centrifuged at 1800 RPM for 20 minutes to separate the PAC from the liquid phase.
- After all bottles were centrifuged, the samples were extracted using a 50 mL pipet and transferred to 40 mL vials until the liquid overflowed (headspace free). The vials were then screened on with Teflon^R lined caps.
- The vials were stored at 4^oC in the dark until chloroform analysis could be performed.

The initial adsorbate concentration was determined using an average of blanks (carbon free) samples. Following equilibration and analyses of liquid phase equilibrium concentrations, surface loadings were calculated by taking a mass balance on the isotherm bottle.

5.1.2.2 Modified Bottle Point Method

(i) Sample Bottle Preparation:

Same as 5.1.2.1 (i)

(ii) Sample Collection:

The samples were collected from the desired clarifier sample point using a glass bottle and covered with a Teflon^R cap.

(iii) Bottle Filling:

- Poured sample from the bottle into a 4 L glass beaker.
- Stirred sample using a Teflon^R lined magnetic stirrer for 5 min.

- Using a Teflon^R tubing and a pipette bulb, siphoned the slurry into the 160 mL bottles, headspace free.
- Filled 3 bottles in each sample run with organic free water.
- Injected 3 different fixed concentrations (each with 3 replicates) of approximately 1:20 dilution of chloroform in methanol solution using a glass syringe and immediately covered with Teflon^R liner and sealed with rubber and aluminum cap.

(iv) Equilibration:

Same as 5.1.2.1 (iii)

(v) Sample Extraction and Storage:

Same as 5.1.2.1 (iv)

5.1.3 Chloroform Analysis

Chloroform analysis were carried out in accordance with EPA method 501.1. A Varian Model 3300 gas chromatograph equipped with flame ionization detector was used in conjunction with a Tekmar^R liquid sample concentrator (LSC-2) and autosampler (ALS) for all analyses. Specific operating parameters are shown in Tables IX and X. Limit of detection was 1.0 ug/L with a precision of $\pm$ 0.3 ug/L.

5.1.4 Quality Assurance and Control

To ensure the reliability of the laboratory analysis results, a quality control program was built-in for all of the above analyses. Details of the quality control program for each of the analyses were:

Purge and Trap Sampler: Tekmar LSC-2 with Model ALS autosampler

Purge	:	11 min
Desorb	:	4 min
Bake	:	10 min
Transfer Lines	:	140°C
Purge Gas	:	Nitrogen at 40 mL/min
Purge Volume	:	5 mL
Trap Material	:	Tenax GC

LSC-2 Set Points

SP1 (Trap)	:	30°C
SP2 (Column Temp at start of GC run)	:	60°C
SP3 (Trap Preheat)	:	100°C
SP4 (Desorb Temp)	:	180°C
SP5 (Trap Bake Temp)	:	225°C

Gas Chromatograph: Varian Model 3300

Column	:	1% SP1000 on Carbopack B (60/80 mesh)
	:	3 m x 2.5 mm

GC Temperatures: Injection Port : 150°C
Column : Hold at 60°C for 0.5 min; increase at 8°C/min to 200°C, hold at 200°C for 5 min.
Detector 300°C

Carrier Gas: Nitrogen 30 mL/min
3 mL/min to injector
27 mL/min directly to column

Detector: Flame ionization
Hydrogen flow: 30 mL/min
Air flow: 240 mL/min

Integrator: Spectra-Physics Model SP-4290

Table IX: Gas Chromatograph Operating Parameters For EPA Method 501.1

GC Clean–Out Procedure

Fill all tubes with 5 mL organic free water

ALS autosampler:

Purge time : 05 min – if previous sample concentration < 200 pp
10 min – if previous sample concentration > 200 pp

Desorb time : 00 min

Bake time : 10 min

SP1 (trap) : 98 °C

Purge Gas Flowrate : 40 mL/min Nitrogen

Desorb Ready
Desorb Preheat : Toggle switch @ Auto

Bake Toggle @ Reset

Remote and thermocouple switches set off

GC: All parameters same as for sample run except:

Oven Temperature : 210 °C
Detector Temperature : 350 °C

After tube #10 has finished, switch "bake" toggle to Auto, step LSC through to bake, and bake out Tenax column for 10 minutes.

Table X: Gas Chromatograph Clean Out Procedure

(i) PAC in Sludge:

Quality control of the PAC in sludge analysis was carried out in two ways: (i) each run of the analysis consisted of 12 samples of which 2 were blanks. The blanks (deionized water) were subjected to the same gravimetric analysis procedure as the slurry samples, i.e. acidify, filtration, volatilization, and combustion. If the blank samples gained or lost more than 10% by weight at any stage of the analysis, the entire run was discarded. During one of the experimental runs, this quality control program helped identify a contaminated acid solution used as reagent; (ii) random samples were sent out for independent analysis to Alberta Environmental Centre for confirmation of the results.

(ii) Carbon Isotherm - Bottle Point Method:

The main source of error in chloroform isotherm analysis is expected to be the volatilization losses. To correct for these losses, blank samples (carbon free) were incorporated during the filling of chloroform mixture into the carbon containing serum bottles. The blanks were incorporated evenly between every 3 samples. The average chloroform concentration of all the blank samples was then used as the initial chloroform concentration in the isotherm calculations.

(iii) Carbon Isotherms - Modified Bottle Point Method:

To ensure reliability of these analyses, all samples were duplicated. In addition, to account for the volatilization losses, spiking of the three different amounts of chloroform was

also carried out in organic free water. The final chloroform concentration of the organic free water was used as initial chloroform concentration for the carbon slurry samples. This quality control program was found inadequate due to large variations in equilibrium concentrations of samples (see Appendix II). In hindsight, more replicates of each sample, additional isotherm points and/or better laboratory technique would have minimized the effect of experimental error on the interpretation of the isotherm results.

(iv) Chloroform Analysis:

To confirm the reliability of the chloroform analysis, each run of ten samples included a blank and a 20 ppb standard.

5.2 Methods for Routine Plant Operations

5.2.1 Turbidity

Turbidity measurements were made using an on-line Hach Ratio 2000 Turbidimeter. A three-point calibration method was carried out once a week or when the once a day lab checks indicated greater than 10% discrepancy.

5.2.2 pH

pH measurements were also carried out by an on-line Prominent Model PHS 014 K2 507 pH meter and probe. Calibration was carried out on a once a week basis.

5.2.3 V/V Solids Percent

100 mL of slurry in a measuring cylinder was allowed to settle for

10 minutes and the settled sludge volume (solid-liquid interface) was noted.

5.2.4 Chemical Feed Confirmation

There were two main types of chemical feed equipment: (i) screw feeders for bulk chemicals; and (ii) meter pumps for liquid chemicals. The screw feeders were calibrated by collecting the chemical in a plastic container for a fixed time period and the delivered weight per unit time was calculated. The chemical pumps were fitted with calibration cylinders on the suction side of the pumps and the liquid volume pumped over a fixed time period was noted.

5.2.5 Clarifier Seeding

(i) Chemicals Required

- Aluminex^{R} (polyaluminum chloride) solution
- Anionic polymer (Percol LT-27^{R}) 0.1% solution
- Dry (powdered) aluminum sulphate
- Dry (powdered) 97% calcium carbonate

(ii) Clarifier Preparation

- Cleaned clarifiers with high pressure water spray to get rid of any sludge leftover from previous use.
- Filled clarifier to overflow level, with river water at rate of 60 L/min (maximum operational flow 150 L/min) while at the same time injecting 20 mg/L Aluminex^{R} and 0.2 mg/L anionic polymer.
- Turned on flocculator and adjusted speed to 12 RPM.

(iii) Seeding

- Poured 25 litres of 0.1% polymer solution into the flocculation chamber.
- Allowed 5 min for mixing, then added 3.5 kg of dry aluminum sulphate into the chamber and increased flocculator speed to 60 RPM for 20 seconds then resumed to previous 12 RPM speed.
- Poured 1 litre of Aluminex^{R} into chamber and again increased speed to 60 RPM for 20 seconds.
- After 5 min, slowly sprinkled over chamber (15 mins.) 6.5 kg powdered calcium carbonate.
- Finally, added 10 litres of 0.1% polymer solution into the chamber and subjected the mixture to 30 seconds of 60 RPM mixing.

(iv) Clarifier Operation

- Observed pinpoint floc (creamy white) almost immediately following the seeding procedure.
- Commenced clarifier operation at rate of 60 L/min and chemical feeds as desired levels (jar test results).
- Observed after 24 hours of continuous operation, clarifier effluent turbidities of $\leq$ 1.0 NTU, increased flow rate (25 L/min every 12 hours) until 150 L/min flow was attained.
- 48 hours after seeding, if turbidities below 5 NTU were not attained, repeated the entire procedure. When turbidities were below 5 NTU, the clarifier was deemed ready for an experimental run.

5.3 Materials

5.3.1 Carbon

Powdered activated carbon used for the experiment was supplied by Transpacific Carbon Company, California. Carbon brand name: WTC; Source Material: Wood; Activation process: Thermal; Apparent density: 400 kg/m^3; Particle size distribution: 90% passing #100-200-325; Ash content: 7%.

5.3.2 Aluminex^R

The coagulant selected for the clarification of water was Aluminex^R 1, a cationic coagulant - an aqueous solution of aluminum hydroxychloride ($Al_n(OH)_mCl_{3n-m}$). The Aluminex^R was supplied in liquid form by Alchem Inc., Burlington, Ontario. The exact composition is proprietary and was not available.

5.3.3 Polymer

An anionic polymer, Percol LT-27^R (polymer of sodium acrylate and acrylamide) was used as a coagulant aid in the clarification process. The chemical was supplied by Allied Colloids, Brampton, Ontario in powdered form.

5.3.4 Chloroform

Chloroform used as adsorbate was obtained in A.C.S. grade from Fisher Scientific Co., Fair Lawn, N.J. 07410. Chloroform Standards used in GC calibration analyses were obtained from Supelco Canada (Oakville, Ontario). Due to volatile nature and health concerns, chloroform was handled with extreme care.

CHAPTER 6: PILOT PLANT EXPERIMENTAL DESIGN

Four experimental runs were designed to be carried out to meet the overall objectives. Each experimental run design was developed on the basis and outcome (where applicable) of the preceding experiments. Each experimental run had specific objectives, an operational protocol and an analysis requirement.

In all of the four experimental runs, the common and non-compromising objective was the optimum operation of the clarifiers (lowest effluent turbidities).

A summary of the four experimental plans is listed in Table XI:

TABLE XI: PILOT PLANT EXPERIMENTAL DESIGN SUMMARY

EXPERIMENT	OBJECTIVE	OPERATING PROTOCOL			ANALYSIS PROTOCOL		
		CLARIFIER * OPERATION	SAMPLING **	DURATION OF EXPERIMENTAL RUN	CARBON CONCENTRATION	CARBON MATERIAL BALANCE	CHLOROFORM ADSORPTION CAPACITY OF SLURRY
RUN 1	To monitor the accumulation of PAC in the clarifier slurry	CLARIFIER C1: (Experimental) PAC Feed: 10 mg/L — CLARIFIER C2: (Control) PAC Feed: 0 mg/L	COLLECT SAMPLES #1, 2, 3, 4: Every hr in C1. Every 3 hr in C2. — COLLECT SAMPLE #5: Every 5 min in C1 & C2 when draining	Up to a maximum of 7 days or when carbon concentration peaks	SAMPLE #2: Analyse all C1 samples — SAMPLE #5: Analyse all C1 samples — SAMPLE #1, 3, 4: Analyse every 6 th C1 sample	NOT REQ'D	NOT REQ'D
RUN 2	To determine: (i) the reproducibility of PAC accumulation characteristics observed in Run 1; and (ii) the impact of recirculating mixer speed on PAC concentration in slurry. Also to confirm the validity of observed carbon values by calculating a carbon material balance on the experimental clarifier	CLARIFIER C1 & C2: (Same as Run 1 above) — For first 60 hrs duplicate Run 1 (i.e. recirc speed, chemical dosages, draining, etc) — After carbon conc. has peaked increase recirc speed by at least 5 RPM for at least 36 hrs and then back down for 36 hrs	COLLECT SAMPLES #1, 2, 3, 4: Every 3 hr in C1 & C2. — COLLECT SAMPLE #5: Every 5 min in C1 & C2 when draining	Continue run until carbon concentration in slurry peaks (no increase over a 48 hr period.) End run after the 72 hr recirculator speed change experiment.	SAMPLE #1, 2, 3, 4: Analyse every 6 th C1 sample — SAMPLE #5: Analyse all C1 samples	REQ'D	NOT REQ'D
RUN 3	To study the impact of increasing PAC feed rate on the concentration achieved in the slurry. To examine the PAC concentration profile in the entire clarifier at peak conditions.	CLARIFIER C1: (Experimental) PAC Feed: 25 mg/L — CLARIFIER C2: (Control) PAC Feed: 0 mg/L	COLLECT SAMPLES #1, 2, 3, 4: Every 12 hr in C1 & C2. — COLLECT SAMPLE #5: Every 5 min in C1 & C2 when draining	End experimental run when carbon concentration reaches peak (no increase over 48 hr period).	SAMPLE #1, 2, 3, 4, 5: Analyse all C1 samples	REQ'D	NOT REQ'D
RUN 4	To evaluate the residual adsorption capacity of PAC accumulated in the clarifier at different time periods and at two separate PAC feed rates, and to re-confirm the reproducibility of carbon accumulating characteristics.	CLARIFIER C1: PAC Feed: 25 mg/L — CLARIFIER C2: PAC Feed: 10 mg/L	COLLECT SAMPLES #1, 2, 3, 4: Every 12 hr in C1 & C2. — COLLECT SAMPLE #5: Every 5 min in C1 & C2 when draining	End experimental run 8 days after carbon concentration has peaked in both clarifiers.	SAMPLE #1, 2, 3, 4, 5: Analyse all samples	REQ'D	REQ'D ANALYSE SAMPLE #2: Every 96 hr from C1 & C2

* *All clarifiers operated at a flow rate of 150 L/min with an optimum dose of Aluminex and Polymer.*

** *Samples #1, 2, 3, & 4 carbon slurry samples from clarifier, sample #5 is sludge drain sample. Not all samples collected were to be analysed.*

CHAPTER 7: RESULTS

The outcome of the experiments can be grouped into two main areas: (i) carbon accumulation; (ii) chloroform adsorption.

Section 7.1 provides in detail, the accumulated concentration of PAC attained in the slurry in each of the four experimental runs, and examines the influence of some variables on the carbon accumulation. Also in this section, comparisons of the PAC material balance and mean PAC residence times amoung the four experimental runs are reported. Finally, a profile of PAC concentration through the clarifier, under operating conditions, is presented.

Section 7.2 summarizes the results of the chloroform adsorption analysis. These analyses include the isotherm results of E.L. Smith raw water and PAC (Transpacific) and the adsorption performance of slurry containing PAC collected every 4 days (96 hours) from the two clarifiers in experiment No. 4.

7.1 Carbon Accumulation

7.1.1 PAC Concentration in Clarifier Slurry

To review the observations made of PAC concentration in clarifier slurry, results of each experimental run are examined separately.

Run No.1: The main objective of this run was to obtain familiarity with the accumulation characteristics of PAC in the clarifier slurry at a PAC feedrate of 10 mg/L. Slurry samples collected from the four clarifier sample points were analyzed for PAC. Figure 14 shows a plot of the average values of the samples with respect to run time in hours. The

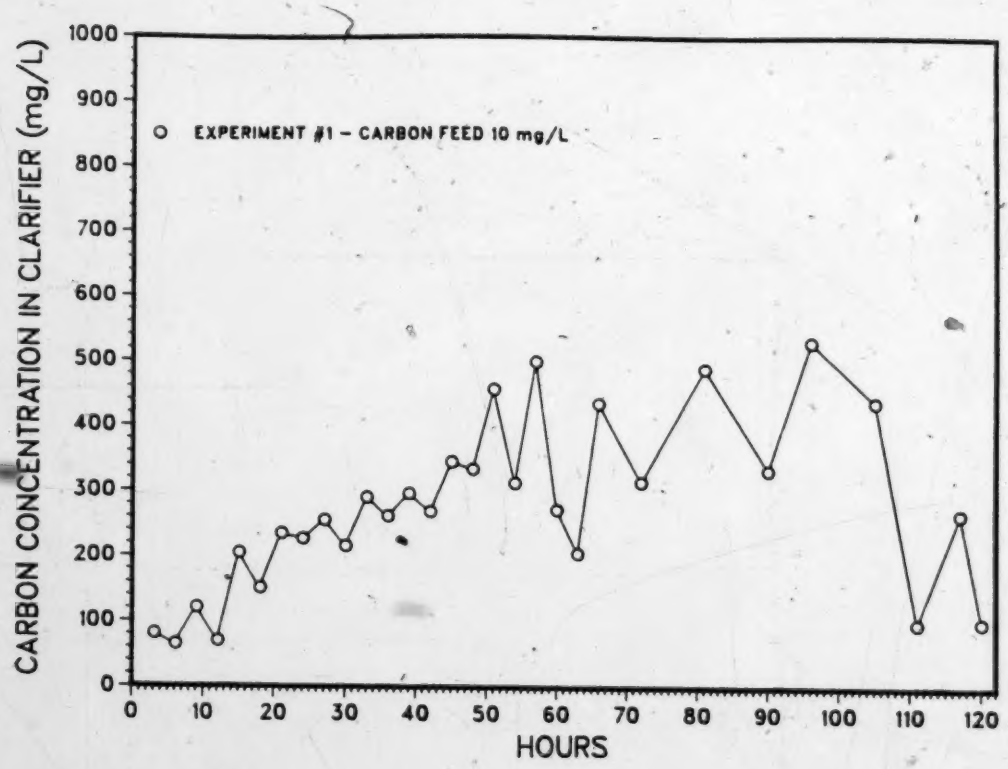


Figure 14: PAC Concentration In Slurry - Experimental Run No. 1

PAC concentration showed a steady increase for about 55 hours (2.2 days) reaching a peak PAC concentration of 500 mg/L. After 55 hours, the PAC concentration fluctuated between 200-500 mg/L. The entire run lasted 120 hours (4.5 days). The fluctuation in concentration was due to an increase in influent turbidity. This is discussed in detail under section 7.1.3.

Run No.2: The second experimental run was designed to confirm the reproducibility of PAC accumulation observed in Run No.1. Figure 15 confirms that the trend of PAC accumulation for the initial 55 hours of Run No.2 depicted, within experimental error, Run No.1. However, in Run No.2, the PAC concentration increase did not end after 55 hours but continued steadily through to experiment termination at 220 hours (Figure 16), when it appeared to have peaked at a PAC concentration of 1600 mg/L.

Run No.3: In this run, the PAC feedrate was increased to 25 mg/L. Figure 17, shows the observed PAC concentrations over the 15 day run time. A steady increase at a rate of 2.5 times the previous run was observed for the first 7 days when the PAC concentration reached over 3000 mg/L. After 7 days until the run ended on the 15th day, the PAC concentration fluctuated between 3200-3900 mg/L. The PAC accumulation had peaked within this range.

Run No.4: In this final run, the two clarifiers in the pilot plant were run simultaneously at two separate feedrates - 10 mg/L and 25 mg/L. Due

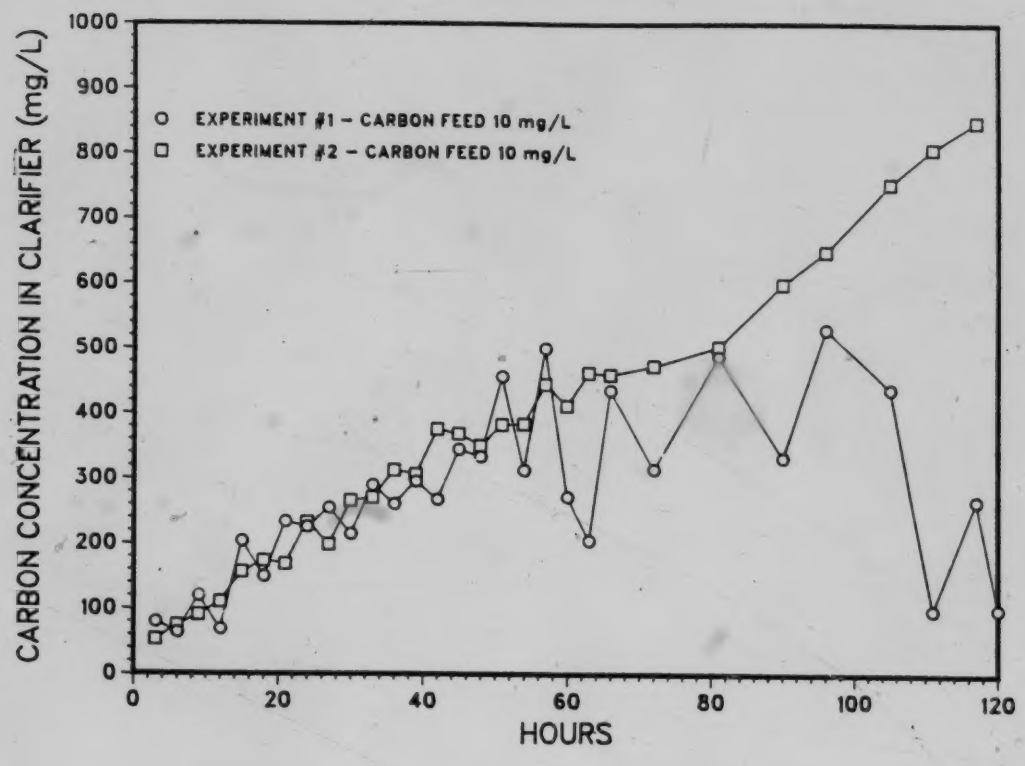


Figure 15: PAC Concentrations in Slurry - Comparison of Experimental Run No. 1 and First Part of Run No. 2

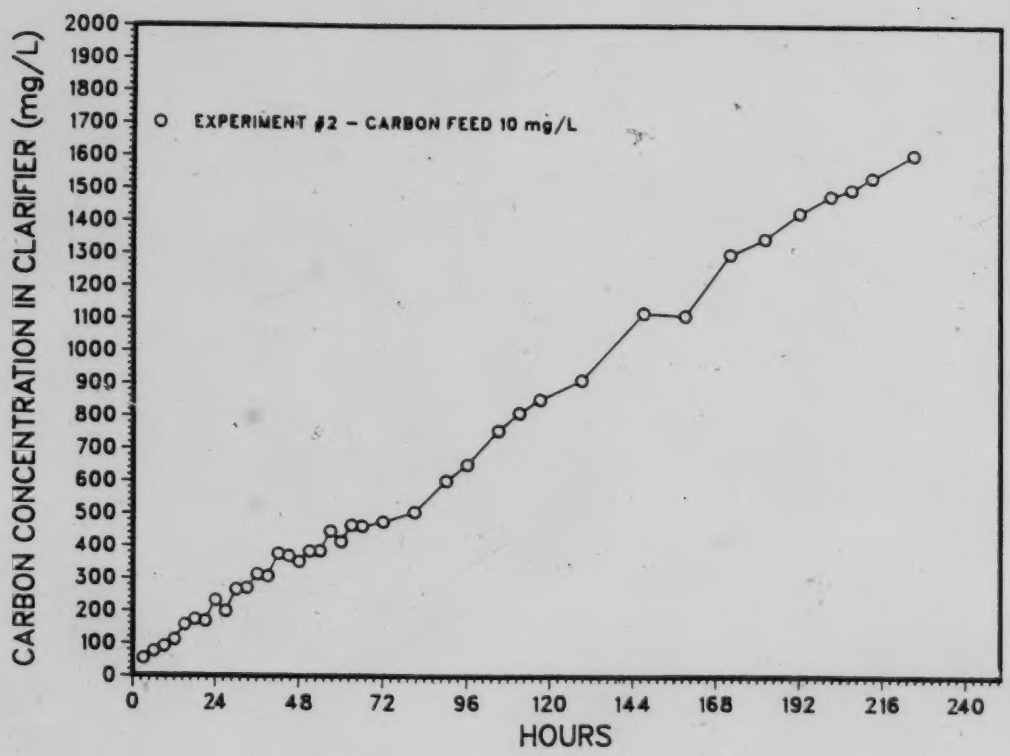


Figure 16: PAC Concentration In Slurry - Experimental Run No. 2

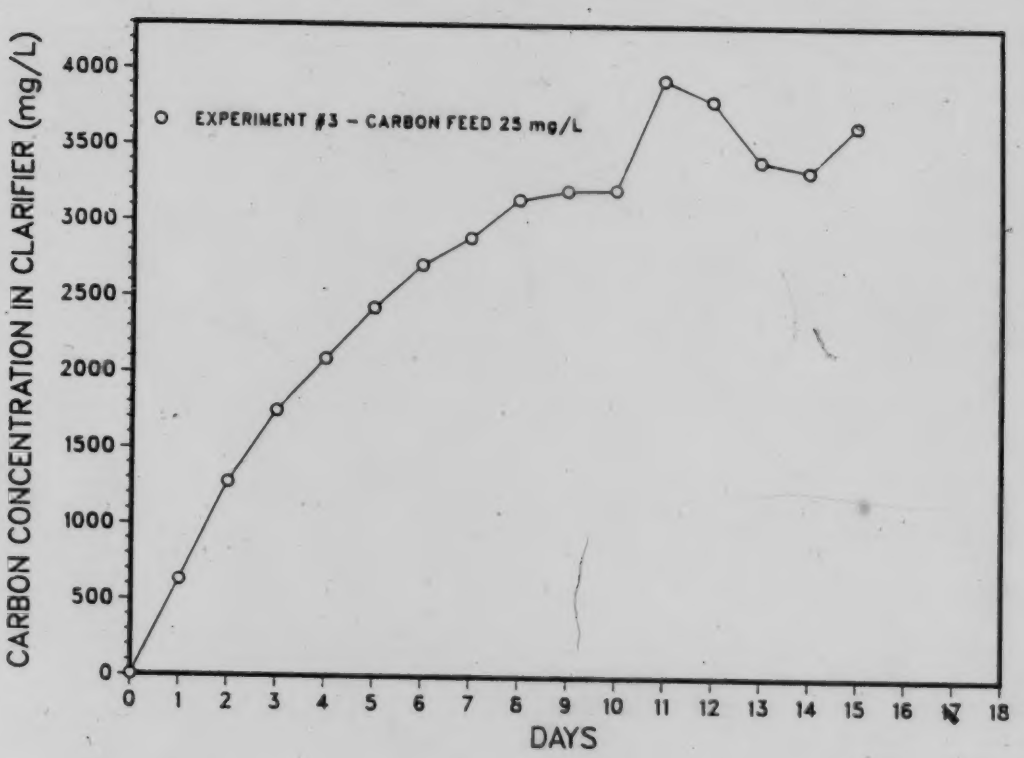


Figure 17: PAC Concentration In Slurry - Experimental Run No. 3.

to conditions experienced during the run which lasted 43 days, the run had to be divided into two phases (A & B). "Phase A" concluded when the PAC concentration in the clarifier slurry was reduced virtually to zero due to an influx of high river turbidity (>450 NTU). "Phase B" commenced as soon as the PAC reappeared in the clarifier slurry. There was about a 2 day break between the conclusion of Phase A and commencement of Phase B, even though PAC was being fed continuously. Phase A run time was 21 days while Phase B run time was 20 days. Figure 18 shows the PAC concentrations observed over the course of Phase A and B for the two PAC feed rates in the two clarifiers. In Phase A at the 25 mg/L feedrate, the PAC concentration steadily increased reaching 4000 mg/L on day 18. Then the concentration dropped by almost 3000 mg/L over the next 3 days. A similar trend was observed in Phase A at the 10 mg/L feedrate. The PAC concentration increased to 1700 mg/L by day 15, it was then fluctuating about 100 mg/L back and forth until day 19 when the concentration began to decrease rapidly. In Phase B, the PAC concentration at both feedrates did not rise at the same rate as its corresponding Phase A concentration, at least for the first 13 days. This was due to continuing high turbidity. Then the PAC concentrations once again began to increase. On day 43 when Phase B run ended, the 10 mg/L feedrate clarifier had reached a concentration of 850 mg/L while the 25 mg/L clarifier had reached 2000 mg/L.

Figure 19 summarizes the PAC accumulation observed in all four experimental runs. This figure shows that while there is evidence of reproducible PAC accumulating characteristics at each feedrate (compare Experiments 2 & 4A, and Experiments 3 & 4A), other variables seem to

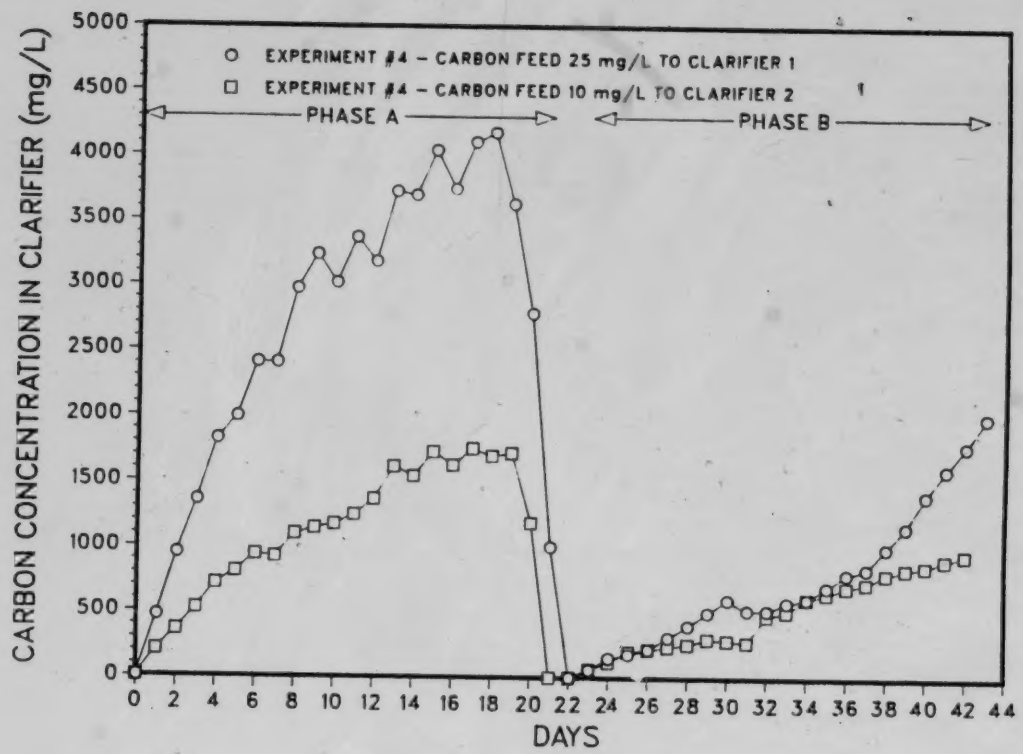


Figure 18: PAC Concentration In Slurry - Experimental Run No. 4

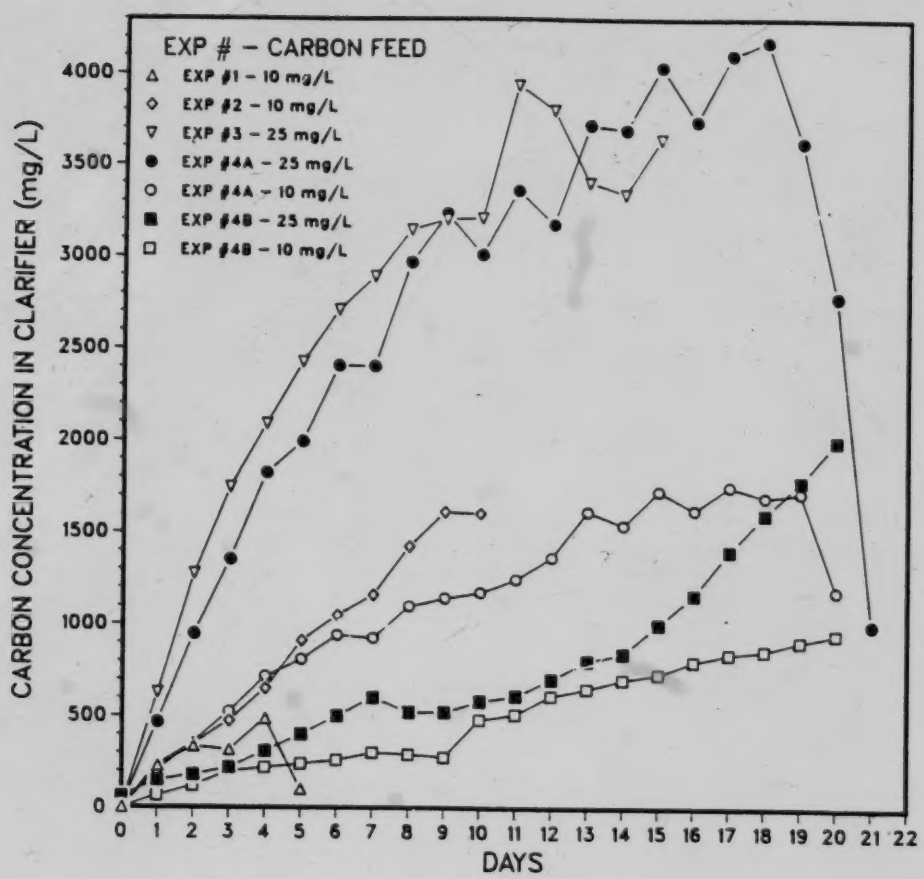


Figure 19: Summary Of PAC Concentrations In Slurry - All Experimental Runs 1 To 4 (Run 4 B shown as starting again at Day 0)

influence the PAC accumulation rate (see Experiment 1 & 4B). These variables were examined and the results in the following sections address the observations.

7.1.2 Clarifier Draining

The principles of material balance would suggest that the amount of PAC retained in the clarifier is equal to the difference of the PAC introduced and the PAC removed. The PAC introduced into the clarifier was through a constant feedrate (10 or 25 mg/L) at a flow of 150 L/min. The PAC removed from the clarifier was almost entirely due to draining of the clarifier, as the PAC loss in the effluent was not detectable. Unlike the feedrate, the draining of the clarifier was not a controlled event. The frequency and duration of the drain was based on settled V/V solids percent of the clarifier slurry monitored in sample points 1 to 4 and the clarifier effluent turbidities.

The impact of the clarifier drains on the accumulated concentration of PAC in clarifier slurry is shown in Figures 20 and 21. The PAC concentrations shown in the clarifier were the average of 4 sample points within the slurry. The drained amounts of PAC shown were calculated on the basis of PAC concentrations of drain samples collected every 5 minutes during a drain and the flow rate of the drain. The figure confirms as expected that the concentration of PAC in the clarifier was inversely proportional to the drained amount of PAC.

7.1.3 Influent Turbidity

An obvious observation made during the four experimental runs was the influence of incoming river turbidity on PAC accumulation in the

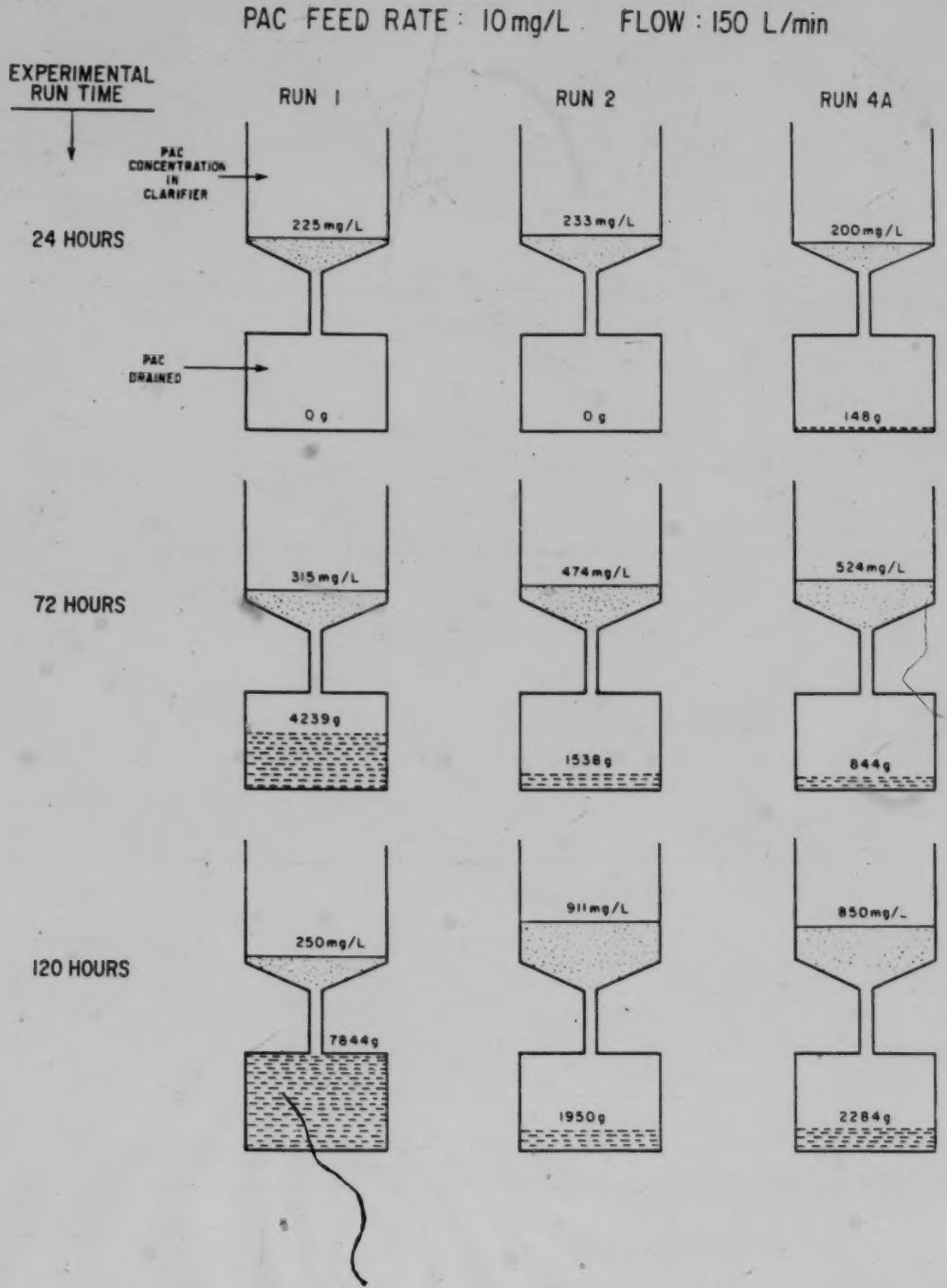


Figure 20: Impact Of Clarifier Draining - PAC Feedrate 10 mg/l

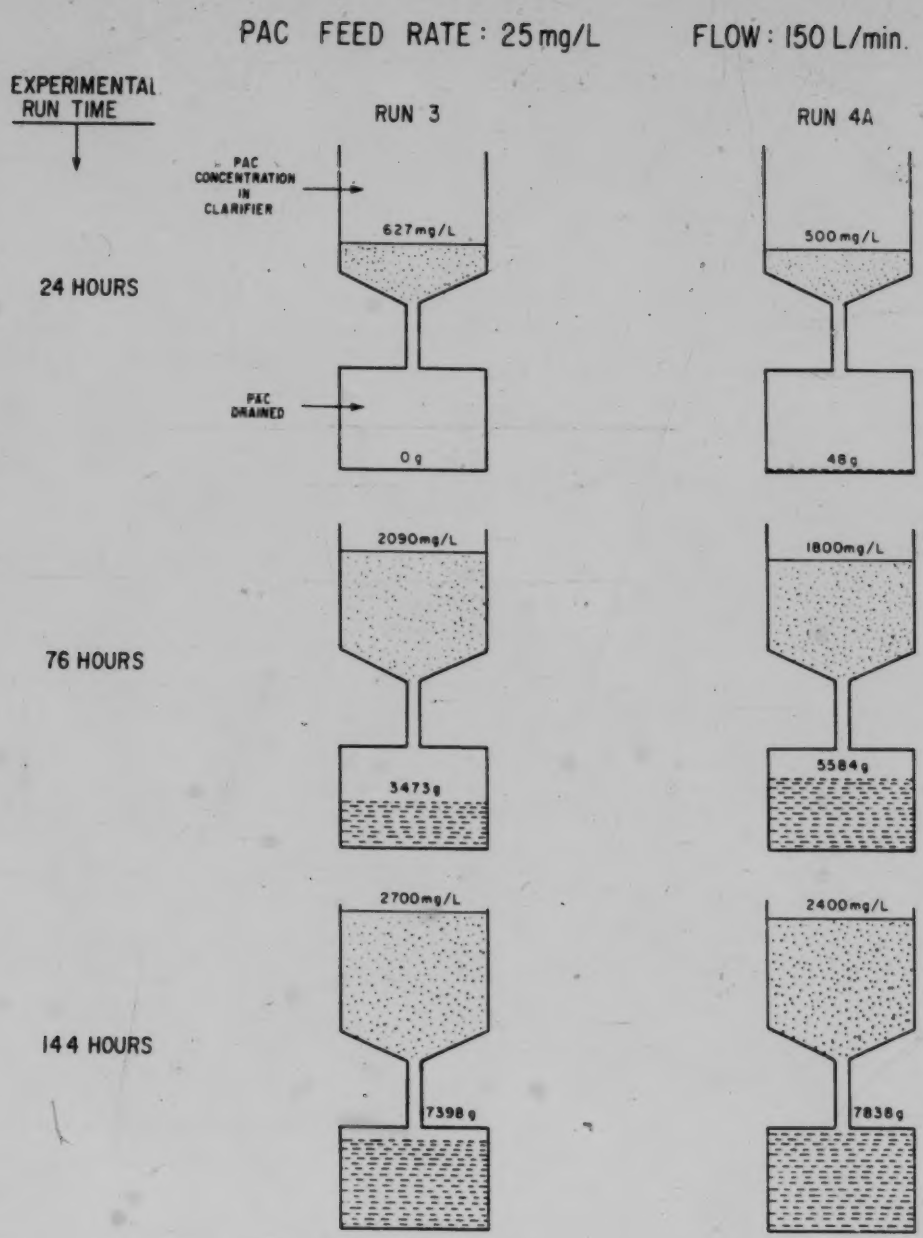


Figure 21: Impact on Clarifier Draining - PAC Feedrate 25 mg/l

clarifier. Figure 22 compares graphically the influent turbidities with the PAC concentrations in the clarifier. It can be observed that a sudden increase in influent turbidities correspondingly results in the decrease in PAC concentration in the clarifiers (compare Experiments 1 and 4A). In addition, the highly turbid water causes a decrease in the rate of carbon accumulation (Experiment 4B). It must be noted that incoming turbidity has a direct influence on the draining requirements in the clarifier. Therefore the observations made with influent turbidity are related to draining of the clarifier, discussed previously.

7.1.4 Recirculator Speed

Another variable that was examined as part of the PAC accumulation experiment was the speed of the clarifier recirculator speed. In experimental run No.2 after the PAC concentration had stabilized, the recirculator speed was increased to 19 RPM for 36 hours and then returned to its original speed (13.5 RPM) for a further 36 hour period. From Figure 23, the increase of the recirculator speed did not show any impact on PAC concentration in the clarifier.

7.1.5 Mean PAC Retention Times

In an attempt to understand the accumulating characteristics of PAC in the clarifier slurry, "Mean PAC Retention Times" were calculated for all experimental runs. These mean retention times were calculated on the basis of PAC material balances derived on the assumption that the PAC in the clarifier was always fully mixed i.e. retention time in the

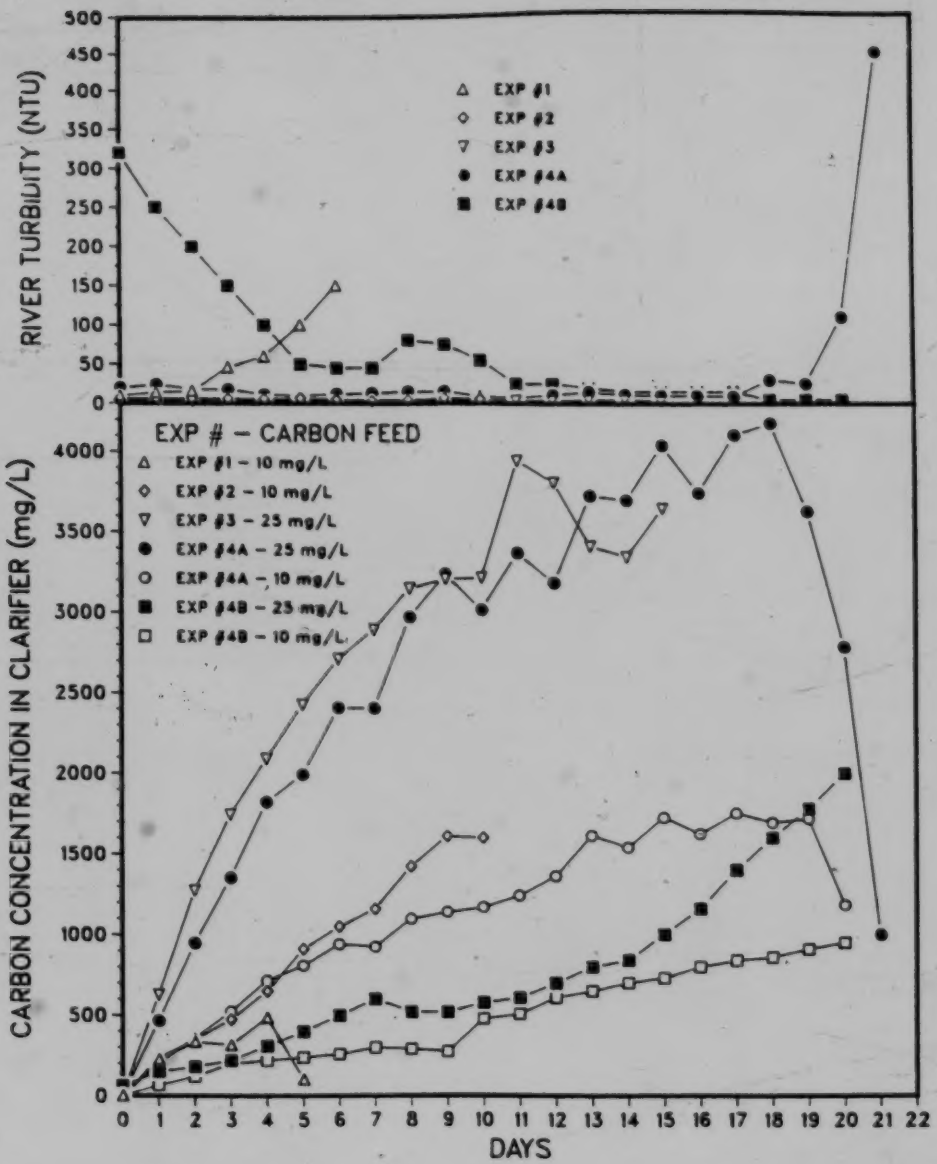


Figure 22: Influent Turbidity And PAC Concentrations In Slurry

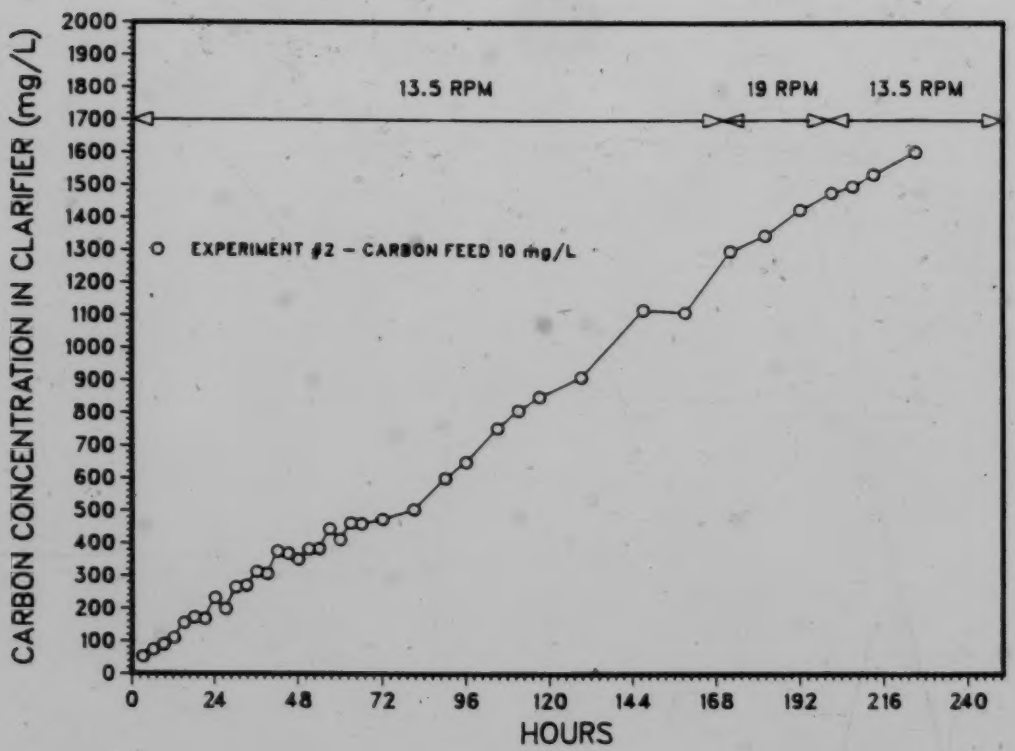


Figure 23: Impact Of Recirculator Speed On PAC Concentration In Slurry

drained slurry was equal to the retention time of the PAC in the clarifier. See sample calculations in Appendix I, also note that average retention time was calculated just prior to each draining event.

Table XII shows the calculated values of mean PAC retention times for the four experimental runs. These times are directly related to the draining frequency, duration and PAC concentration of the drains. The higher the amount of PAC drained, the lower the mean retention time of the PAC calculated i.e. PAC in clarifier is fresh.

7.1.6 PAC Profile in Clarifier

To provide a further insight into the accumulating characteristics of PAC in the clarifier, a PAC concentration profile was determined after PAC concentrations had peaked in experimental run No.3. Figure 24 compares the PAC concentrations observed through the clarifier under operating conditions to the profile after 24 hours of a subsequent complete mixing of the clarifier (recycling clarifier drain back into the clarifier influent). The results before and after mixing show little change in concentration except in the bottom drain and in the area above the tube settlers. This indicates that the accumulated PAC concentration is well distributed throughout the clarifier during normal operating conditions.

7.2 Chloroform Analysis

7.2.1 Isotherm for PAC in River Water

The first part of the adsorption analysis involved the development of a chloroform isotherm for Transpacific PAC in E.L. Smith raw water.

RUN DAYS	RUN # PAC FEED ===>	MEAN PAC RETENTION TIMES (HOURS) 1 10 mg/L	2 10 mg/L	3 25 mg/L	4 10 mg/L	4 25 mg/L
2		15	22	24	24	24
4		27	43	47	49	51
6		-	65	66	67	68
8		-	-	85	90	39
12		-	-	116	132	130
16		-	-	-	168	167
20		-	-	-	206	200
24		-	-	-	9	9
28		-	-	-	14	19
32		-	-	-	12	13
36		-	-	-	32	45
40		-	-	-	53	58

Table XII: Mean PAC Retention Times Experimental Runs 1 - 4

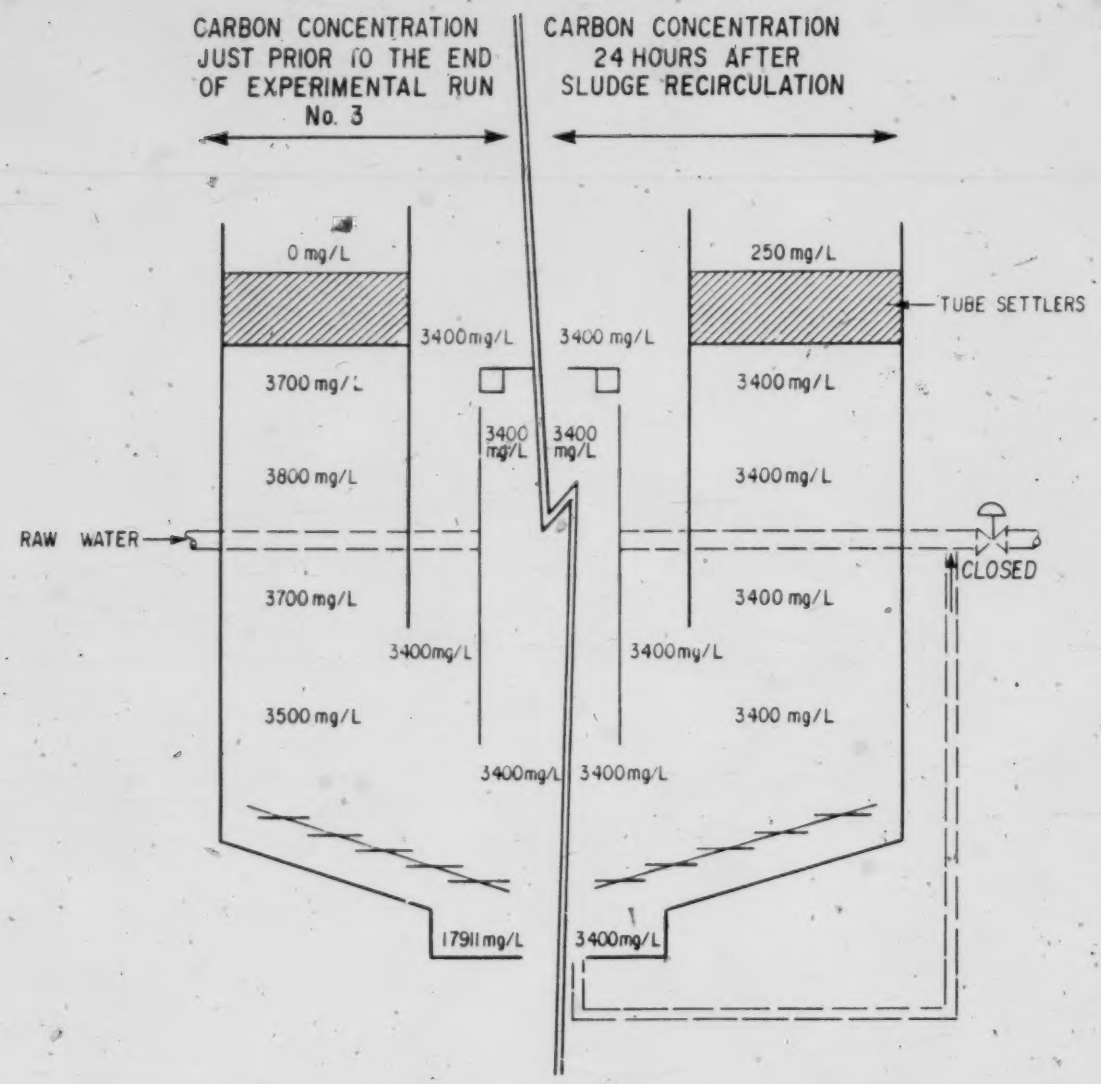


Figure 24: PAC Concentration Profile Through The Clarifier

This isotherm was to be used as a benchmark for subsequent adsorption analysis that involved the development of isotherms for the clarifier slurry.

Figure 25 shows the isotherm data obtained under these conditions. The Freundlich Isotherm fit is good with a correlation coefficient of 0.97.

7.2.2 Isotherms for Clarifier Slurry with PAC

In experimental run No.4, clarifier slurry samples were collected from both clarifiers every 4 days and subjected to isotherm analysis. The results obtained from these analysis are shown in Figures 26 and 27. Also on these figures is the plot showing the isotherm for PAC in river water. While there is a cluster of data points, the two figures show that, with the exception of a few, the general trend of the individual clarifier slurry isotherms remains very close to the benchmark isotherm.

7.2.3 Effects on PAC Adsorption Capacity

The cluster of data points in Figures 26 and 27 make their interpretation difficult. For the purpose of data analysis, the plots were divided into 3 groups (GROUP I: 4, 8, 12 days; GROUP II: 16, 20, 24 days; GROUP III: 28, 32, 36, 40 days). These plots were then examined with respect to the following variables.

7.2.3.1 Sampling Days (Experimental Run Time)

Figures 28 and 29 show the chloroform slurry isotherms on the basis

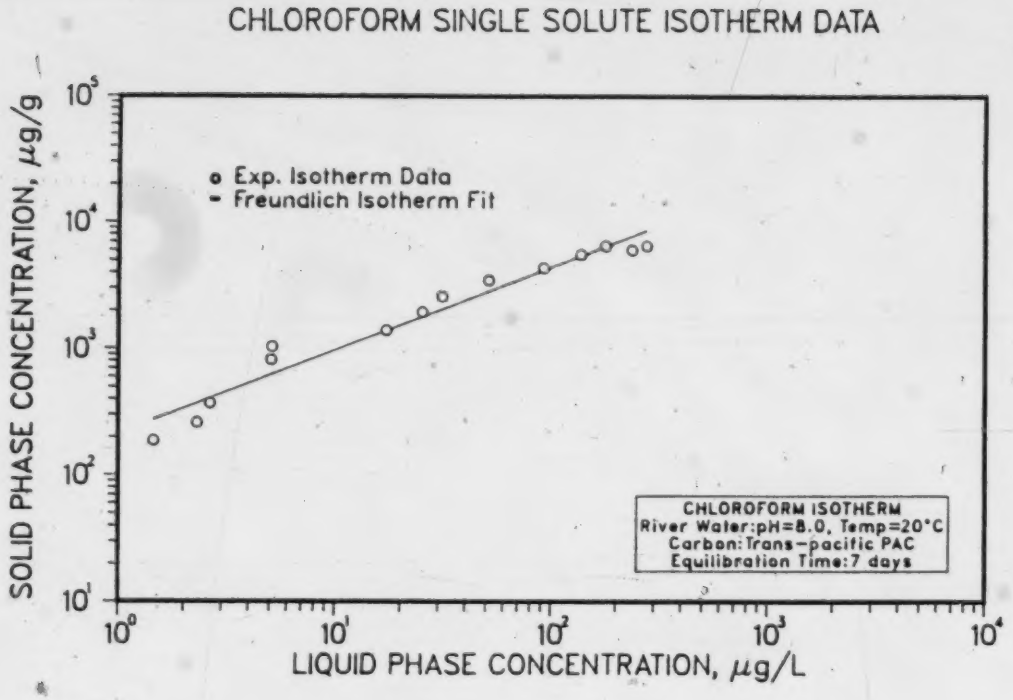


Figure 25: Chloroform Isotherm For PAC In River Water

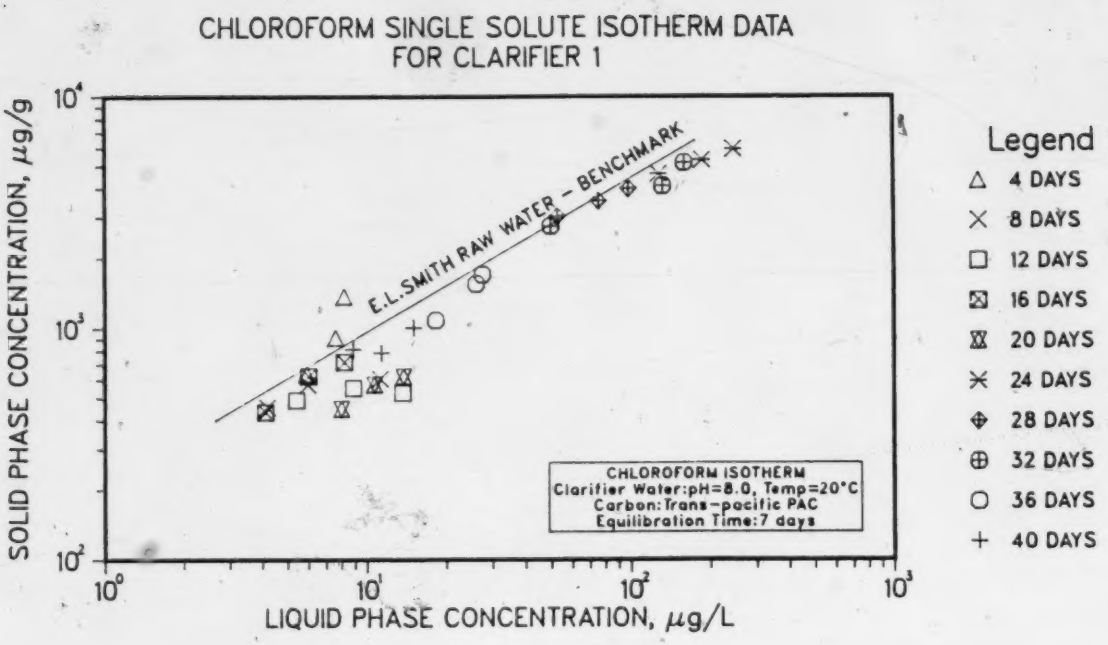


Figure 26: Chloroform Isotherm Points - Clarifier No. 1

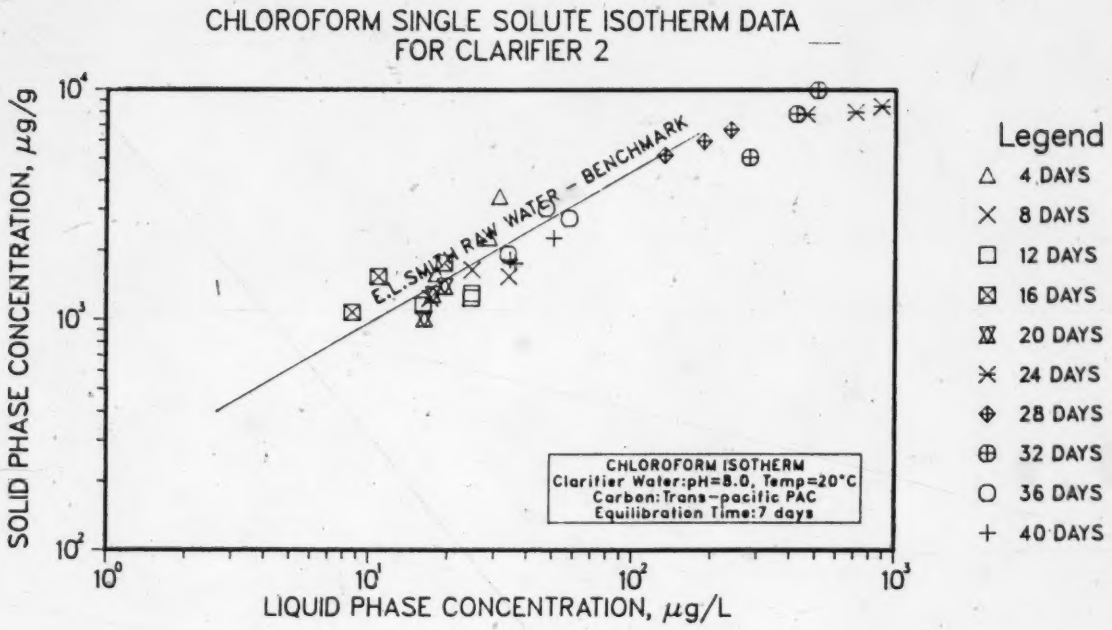


Figure 27: Chloroform Isotherm Points - Clarifier No. 2

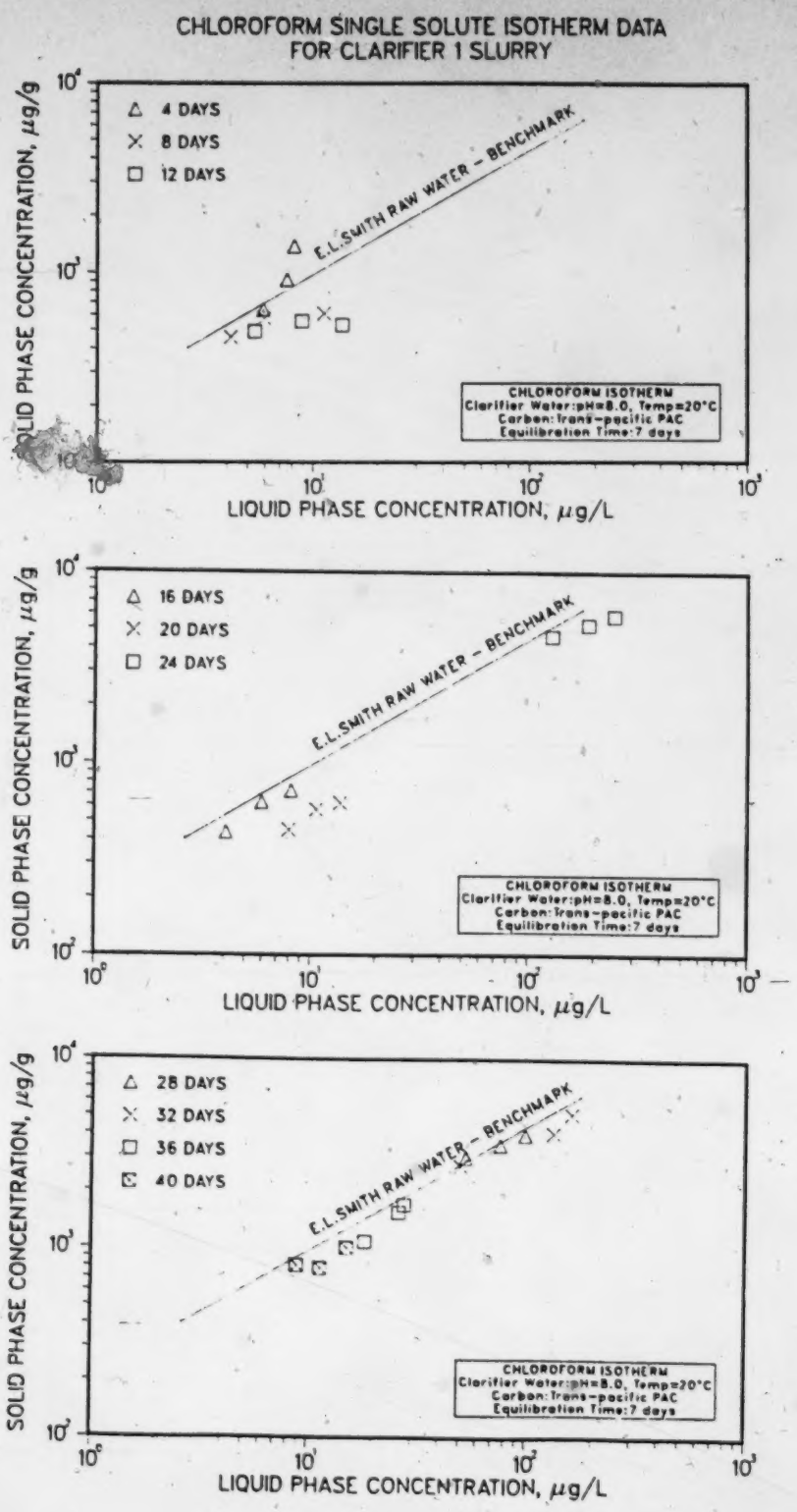


Figure 28: Chloroform Isotherms for Clarifier No. 1 - With Respect to Experimental Run Time

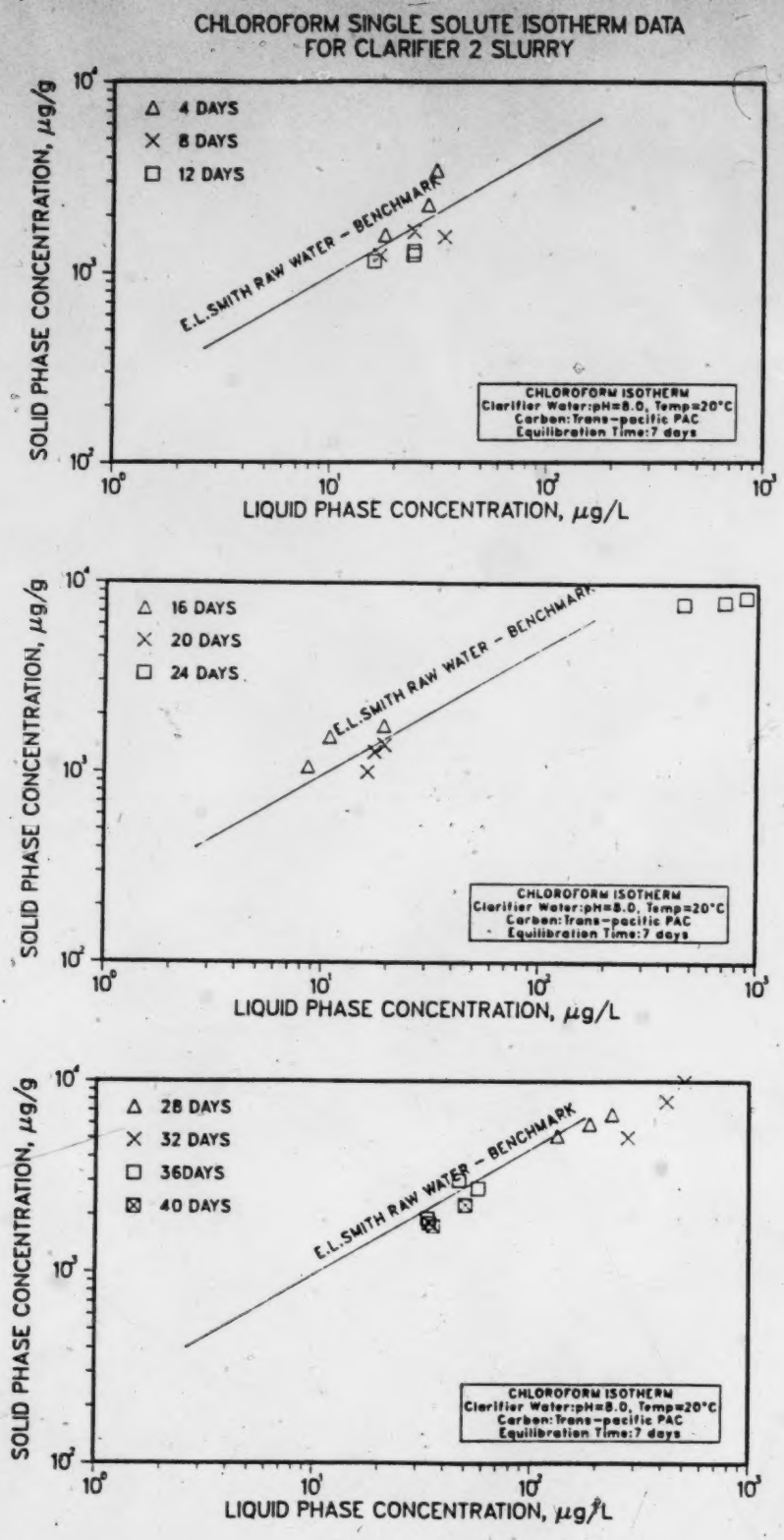


Figure 29: Chloroform Isotherms for Clarifier No. 2 - With Respect to Experimental Run Time

of the days of experimental run on which the samples were collected. In comparing the isotherms for days 4, 8 and 12 a decline in capacity is observed in clarifier #1 (Figure 28), and clarifier #2 (Figure 29). For days 16, 20 and 24, both figures show a sudden increase in capacity for slurry collected on day 24. Finally for days 28, 32, 36 and 40, clarifier #1 isotherms for day 28 and 32 are too close to each other, but higher in capacity than day 36 and 40. Clarifier #2 isotherms for 28 - 40 days are not conclusive.

7.2.3.2 Mean PAC Retention Times

In earlier analysis on PAC accumulation, the "Mean PAC Retention Time" showed that the PAC retention time in the clarifier did not always correspond with the experimental run time (i.e. sampling days). This was particularly true in experiment run No.4. Figures 30 and 31 represent the same plots as those in Figures 28 and 29 except this time the sampling days are shown with the mean PAC retention times. These plots now begin to explain some unexpected observations made. For example, in both clarifiers day 24 isotherms show increased capacity from day 16 and 20; Figures 28 and 29 show that on day 24, the mean PAC retention time is drastically reduced (i.e. PAC is fresh). Also in clarifier #1, day 28 and 32 isotherms were noted to be very close to each other. The PAC retention times now confirm that on both days, the PAC age was almost the same. The isotherm data were rearranged, this time into 3 groups of PAC retention times: (Group I: Low Retention Time (9-19 Hrs); Group II:

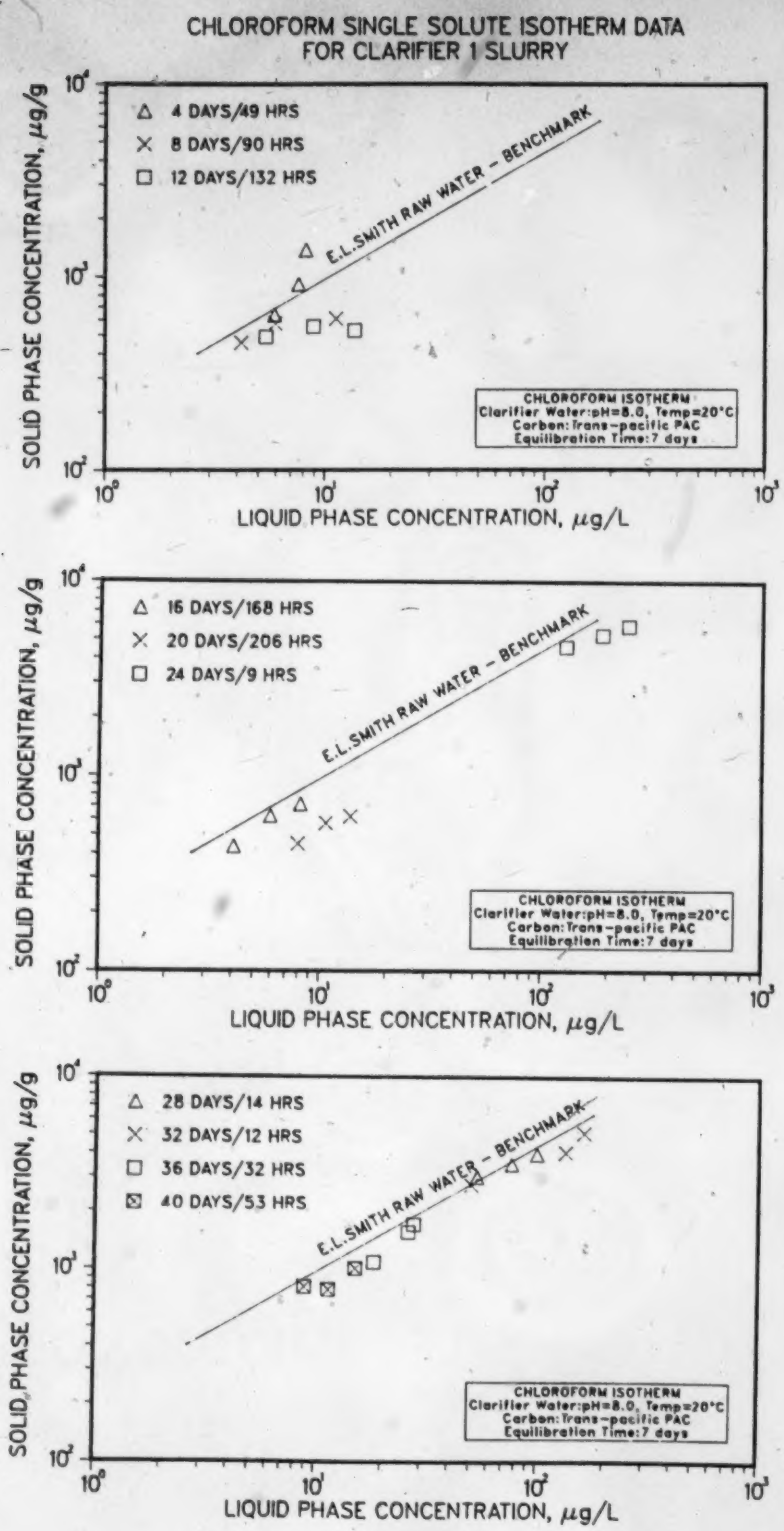


Figure 30: Chloroform Isotherms for Clarifier No. 1 - With Respect to Experimental Run Time and Showing PAC Retention Time

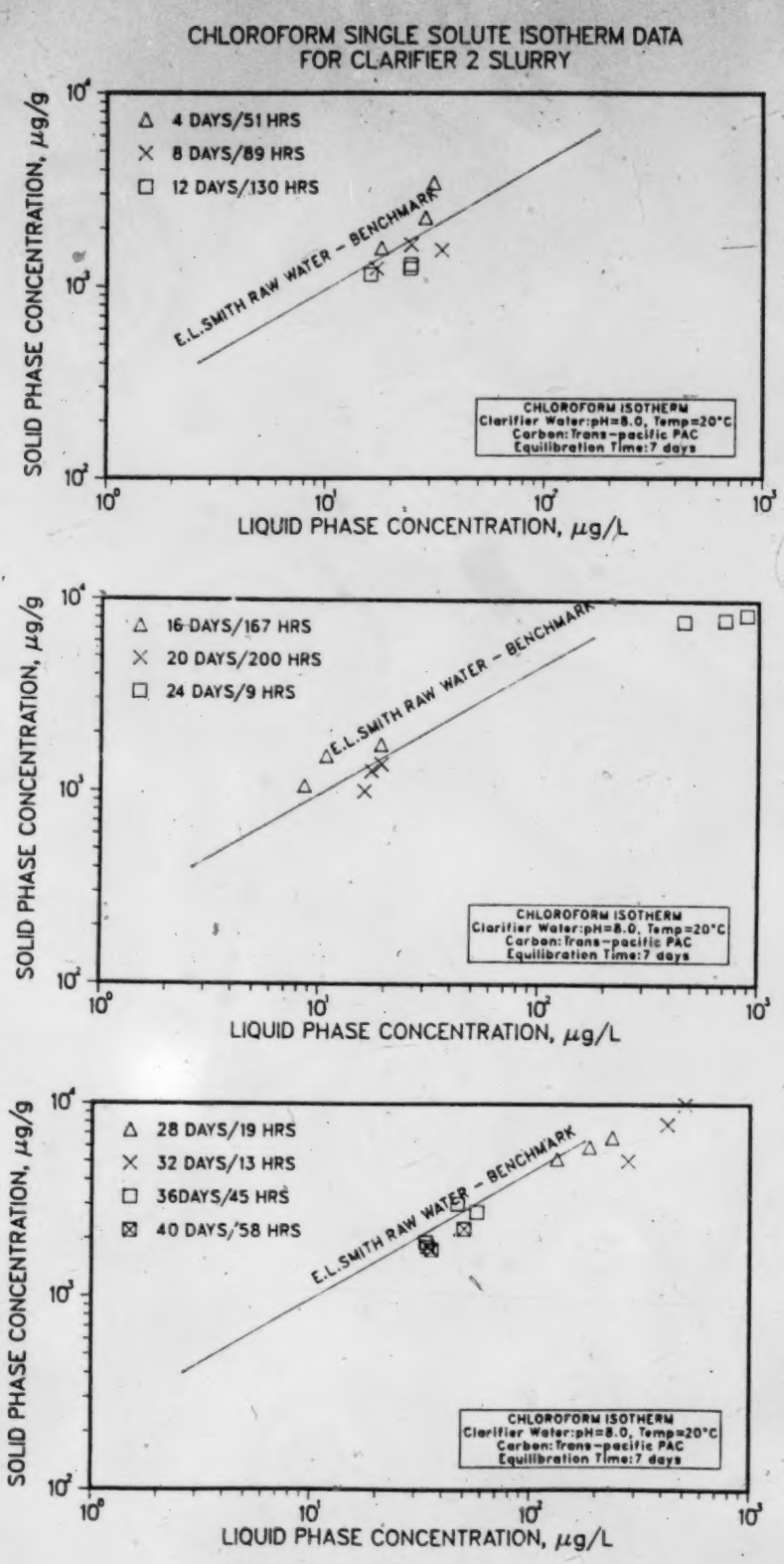


Figure 31: Chloroform Isotherms for Clarifier No. 2 - with Respect to Experimental Run Time and Showing PAC Retention Time

Medium Retention Time (32-58 Hrs); Group III: High Retention Time (90-206 Hrs)) as shown in Figures 32 and 33. Based on these plots, a relationship between PAC adsorption behavior and PAC retention times appears to exist. Because almost the same three chloroform concentrations were spiked in each set of isotherm bottles, the plots reflect the increasing amount of carbon in the slurry as retention time increases. At low retention times, less carbon is present so the residual liquid phase concentrations are high. These decrease with increased retention time. For the clarifier with PAC feedrate of 25 mg/L (Clarifier #1, Figure 32), there appears to be some loss in PAC adsorption capacity compared to the benchmark isotherm at the longer retention times. To confirm this observation PAC capacities (calculated for an assumed liquid phase concentration of 10 ug/L) were plotted against Mean Retention Times, Figure 34. The figure, though not very conclusive, suggests for clarifier 1 a declining PAC capacity with increased PAC retention time.

7.2.3.3 PAC Background Organic Exposure

Another variable that can influence the PAC slurry adsorption capacity would be its exposure to background organics. While no provisions were made in the design of the experiments to monitor background organics in river water, a background organic factor was later developed on the basis of river color that was monitored. The calculations and background organic factors derived for the purpose are summarized in the Appendix I. Figure 35 shows the plot of PAC adsorption capacities against background exposure units in TCU-Hr/kg. For clarifier #1, the plot appears to show a trend

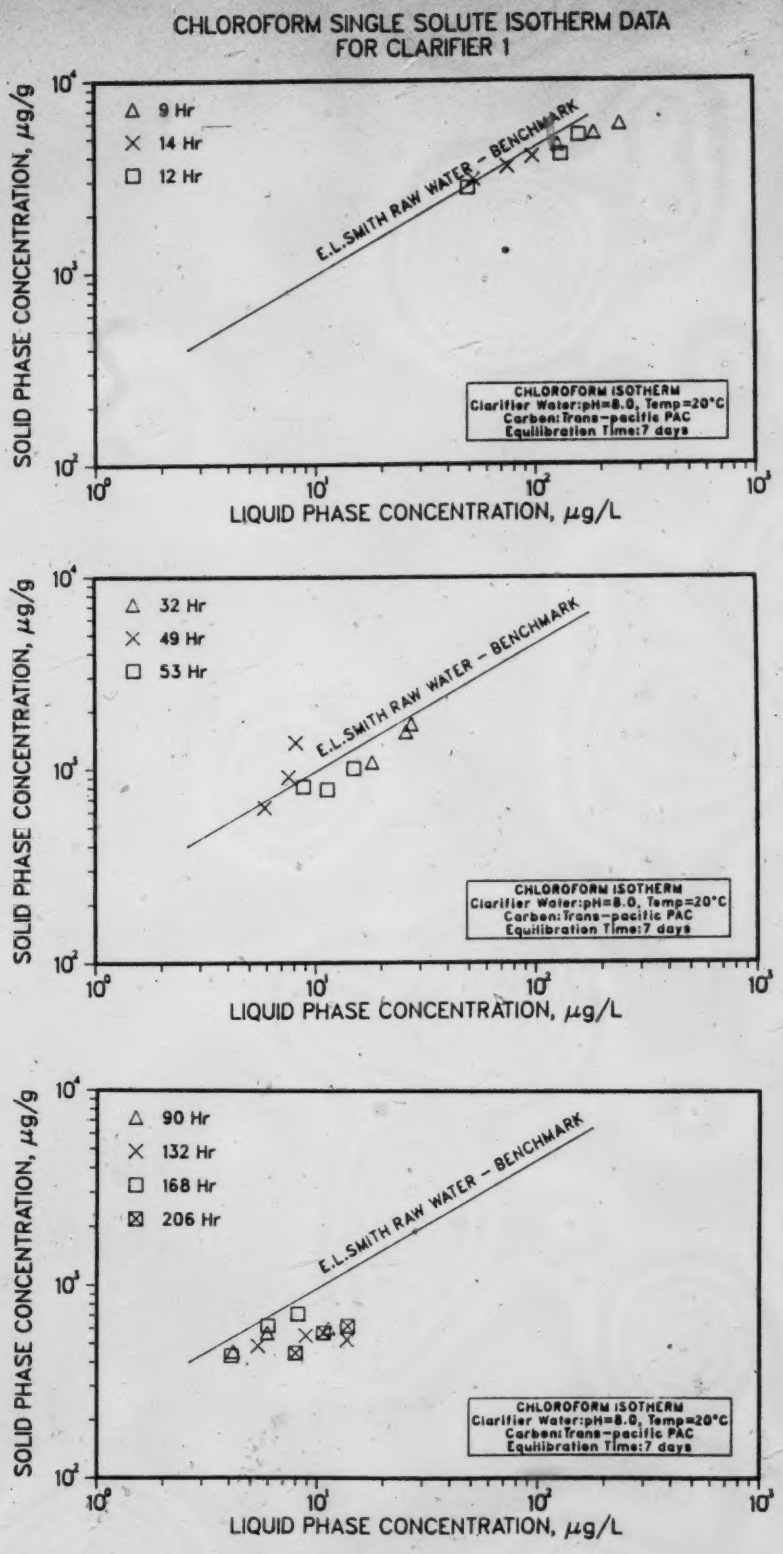


Figure 32: Chloroform Isotherms for Clarifier No. 1 - Regrouped with Respect to PAC Retention Time

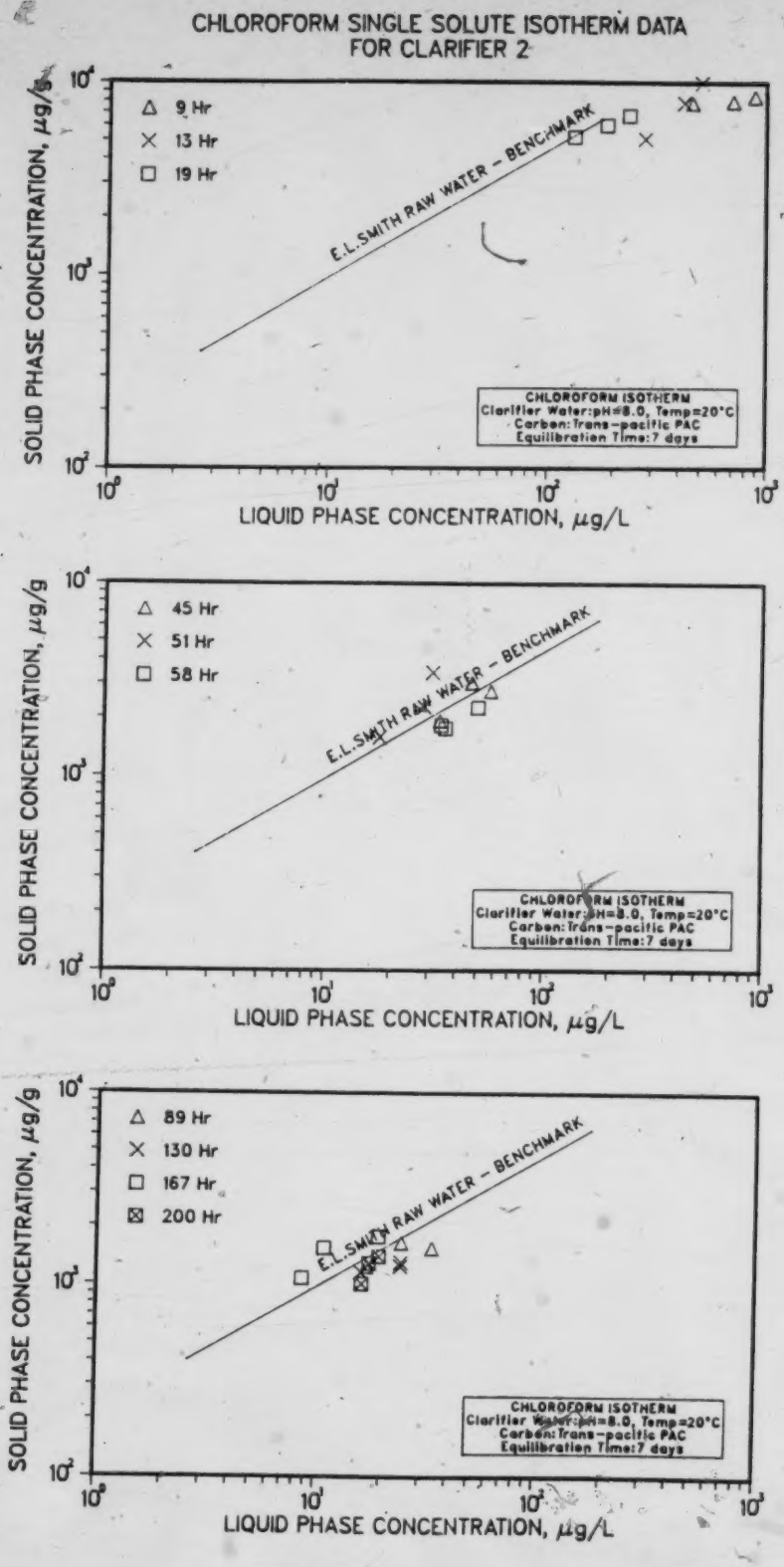
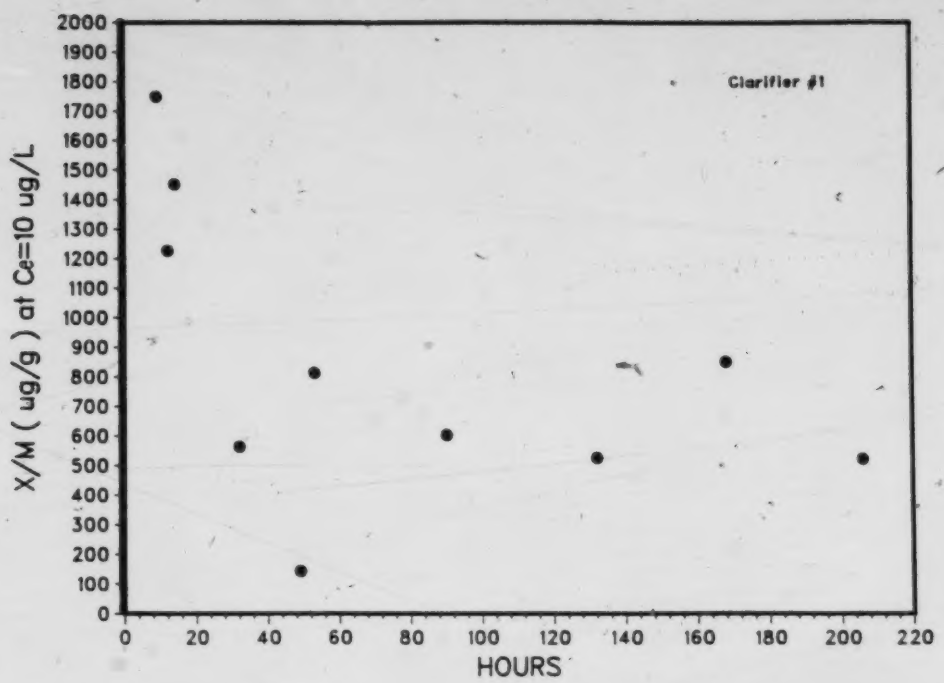


Figure 33: Chloroform Isotherms for Clarifier No. 2 - Regrouped with Respect to PAC Retention Time



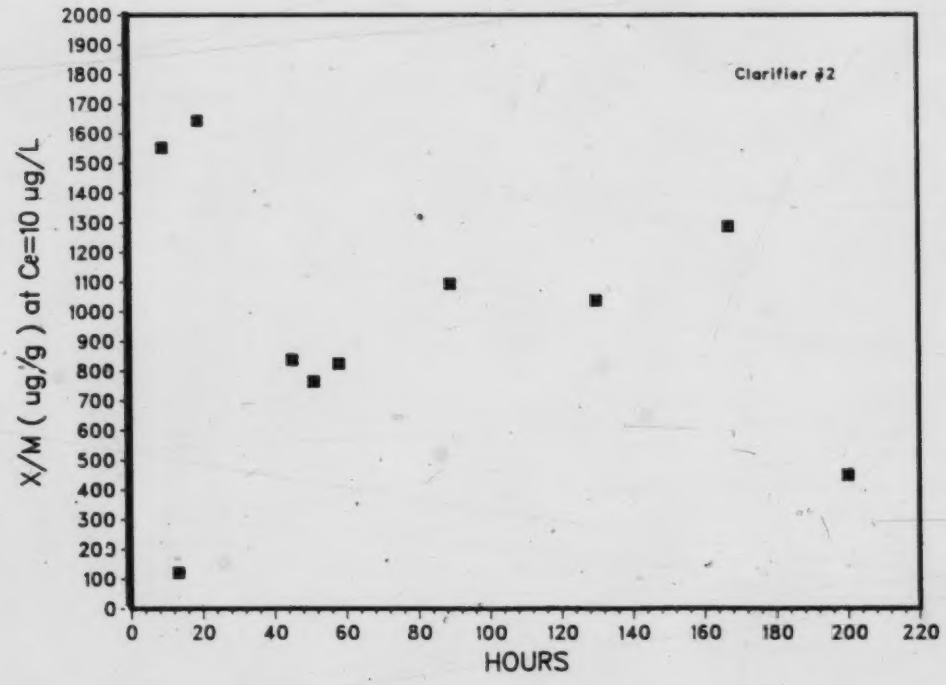


Figure 34: Chloroform Adsorption Capacity vs Mean PAC Retention Times

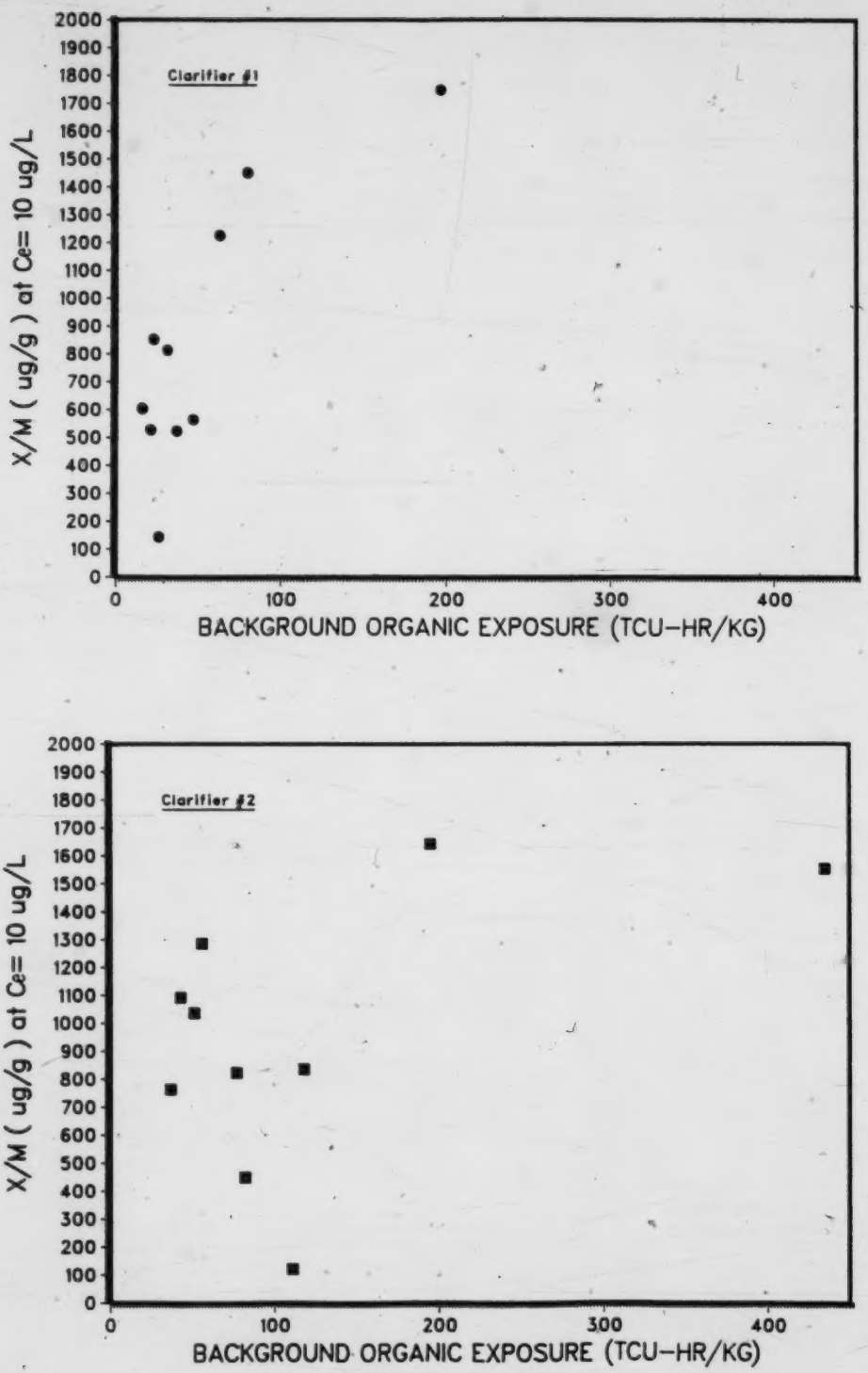

Clarifier #1
X/M (ug/g) at Ce= 10 ug/L
BACKGROUND ORGANIC EXPOSURE (TCU-HR/KG)
Clarifier #2
X/M (ug/g) at Ce= 10 ug/L
BACKGROUND ORGANIC EXPOSURE (TCU-HR/KG)

Figure 35: Chloroform Adsorption Capacity vs Background Organic Exposure Factor

which is the reverse of that expected, while for Clarifier #2 it fails to show any definate trend and is inconclusive. No further explanation for these results was apparent.

CHAPTER 8: DISCUSSION AND IMPLICATIONS

This research effort was designed to provide an understanding and insight into PAC accumulation and dynamics in the solids contact slurry recirculating clarifier. The results obtained do provide some extremely valuable information on PAC in a SCSRC.

The experiment showed that the concentration of PAC in the SCSRC used for this experiment and under certain operating conditions reaches almost 4000 mg/L. The accumulation rate is dependent on the PAC feedrate and clarifier drain rate. The drain rate is strongly influenced by incoming water conditions, in particular turbidity (suspended matter). An influx of high turbidities necessitates excessive draining of the clarifier and this hinders the build-up of PAC in the clarifier.

The profile of accumulated PAC through the clarifier also revealed that PAC is evenly distributed in the entire clarifier. The exception is the area above the tube settlers, which showed no PAC presence. This is a new finding that has not previously been investigated, and suggests a substantial increase in contact between the PAC in the clarifier and the incoming water. Considering that: (i) the SCSRC operates on the basis of recirculating four times the volume of incoming water; and (ii) the findings of this experiment now confirm the presence of a highly concentrated PAC blanket distributed evenly in the settling area enabling PAC contact settling; the process offers a considerably longer period of PAC contact than is usually possible in conventional treatment (taken to be sequentially: coagulation, flocculation and sedimentation).

Over the speed range investigated the SCSRC recirculator speed showed no impact to PAC concentration in the clarifier slurry. However, it must be noted that the recirculator speed is important as far as keeping the solids suspended in the slurry. Once an optimal speed of the recirculator has been determined in the operation of the clarifier, further speed increases have no influence on PAC concentration.

This research was carried out in Edmonton, where the North Saskatchewan River (N.S.R.) was the source of the clarifier influent water. The findings of this research are considered applicable to any facility that practices PAC addition into a SCSRC. However, the results must be viewed in perspective. For example: the high turbidity (>450 N.T.U.) in a short span in the N.S.R. is not necessarily a common occurence in other surface water sources.

This research also provides some insights into developing operating strategies for PAC use in a SCSRC. In the experiments conducted, the operation of the clarifier (includes draining) was based on attaining the lowest clarifier effluent turbidities. Sometimes faster build-up of PAC can be attained if the frequency and duration of clarifier draining are controlled. Also this research showed a specific PAC accumulation rate and PAC distribution profile in the clarifier. In applying this data, allowances must be given to the size of the clarifier and flowrate into the clarifiers, both of which will have a strong influence in PAC accumulation and distribution. The results obtained in this experiment are specific to conditions and pilot clarifiers used for the purpose of this study.

Chloroform was used as a solute for adsorption in determining the

capacity of PAC in clarifier slurry. Chloroform's selection was based on its universal concern in drinking water, wide information base and analytical technique availability.

The bottle point method to produce chloroform isotherms is widely used. The technique has been fine tuned due to its extensive use at the University of Alberta, as reflected in the correlation coefficient of 0.97 obtained for chloroform isotherm for dry Transpacific PAC (see Figure 25). However, the modified bottle point method used to determine chloroform isotherms for clarifier slurries containing PAC, was used for the first time and in retrospect many experimental errors were realised through the course of these analysis. The reliability of the results is questionable as confirmed in the correlation factors listed under Table XIII. The procedure was too expensive and time consuming to enable repeating of the analysis. Also, the samples had been discarded and the repeat of the analysis would have entailed the repeat of the entire clarifier experimental run. In addition, these analysis were considered secondary to the prime objective of this study: to understand the accumulation of PAC in an SCSRC.

In spite of their reliability, the chloroform isotherm data did show an interesting trend. The slurry containing PAC showed, though not conclusively, some decrease in adsorption capacity with increased PAC retention time. The higher the age of PAC in the slurry, the lower its capacity to adsorb chloroform. This trend would be expected from the pre-loading effects discussed in Chapter 3. Another trend that should also be expected is the decrease in PAC adsorption capacity with increase in exposure to background organics. An attempt was made to

ISOTHERM DESCRIPTION	CORRELATION COEFFICIENT
E.L. SMITH RAW WATER	0.97 *
EXPERIMENTAL RUN 4 (CLARIFIER 1)	
4 Days	0.94
8 Days	0.88
12 Days	0.63
16 Days	0.98
20 Days	0.97
24 Days	1.00 *
28 Days	1.00 *
32 Days	0.98
36 Days	1.00 *
40 Days	0.81
EXPERIMENTAL RUN 4 (CLARIFIER 2)	
4 Days	0.92
8 Days	0.76
12 Days	0.92
16 Days	0.88
20 Days	0.93
24 Days	0.91
28 Days	1.00 *
32 Days	1.00 *
36 Days	0.83
40 Days	0.97

* *CORRELATION EXISTS AT THE 5 PERCENT LEVEL OF SIGNIFICANCE – (Kennedy & Neville, 1976)*

Table XIII: Summary of Isotherm Correlation Factors

quantify the background organics exposure. Using average river color and mean PAC retention time a background organic exposure factor was derived. However, no plausible relationship could be found between PAC adsorption capacity and this factor. This outcome may have to do with the fact that color is not a reliable means of establishing the background organics exposure.

In summary, this research effort: (i) confirms that massive amounts of PAC can be accumulated in an SCSRC; (ii) identifies some variables that affect the rate of PAC accumulation; (iii) on the basis of PAC profile in the clarifier, confirms the process offers increased PAC contact; and (iv) shows that the adsorption capacity of PAC slurry decreases with increase in time the PAC was retained in slurry. In addition, a method to quantify the concentration of powdered activated carbon in the clarifier solids slurry was successfully developed.

All of the above findings do provide for the first time, some very valuable operating information on PAC addition in SCSRC. This information now forms a basis for initiating further research on actual removal efficiencies of various organic contaminants by PAC accumulation in a SCSRC.

CHAPTER 9: CONCLUSIONS

1. A high concentration of powdered activated carbon (>4000 mg/L) can be achieved in the slurry of the solids contact slurry recirculating clarifier (SCSRC). The accumulated concentration is dependent on the feedrate of powdered activated carbon. In this research, using a pilot scale SCSRC, a steady state appears to be achieved, at which the maximum accumulated carbon concentration in the slurry reaches approximately 160 times the feedrate.

PAC Feedrate @ 150 L/min	Max. PAC Concentration in Slurry Blanket
25 mg/l	4100 mg/L
10 mg/l	1700 mg/L

2. Influxes of high turbidity water (100 - 450 N.T.U.) reduced substantially the concentration of powdered activated carbon in the pilot clarifiers, inspite of continued carbon feed. The carbon loss is directly attributable to the increased sludge wasting rate required to maintain clarifier operation.

3. The concentration of PAC in the pilot solids contact slurry recirculating clarifiers is evenly distributed through the entire clarifier with the exception of the settling area above the tube settlers. This suggests that the process offers a considerably longer period of powdered activated carbon contact than is possible

in conventional drinking water treatment (taken to be sequentially: coagulation, flocculation and sedimentation).

4. Some decrease in adsorptive capacity of the slurry containing powdered activated carbon was observed as the mean carbon retention time in the slurry increased.

5. No plausible relationship was found between the adsorptive capacity of the slurry containing powdered activated carbon and the background exposure levels of organic matter, measured as color.

6. The modified bottle point method, as applied in this experiment, to derive the chloroform isotherm data for slurries containing PAC contributed to the poor reliability of the results. Conclusions 4 and 5 above must be viewed in context of the questionable reliability of this method.

CHAPTER 10: RECOMMENDATIONS

1. Based on the information obtained from this research (quantification and distribution of powdered activated carbon in solids contact slurry recirculating clarifier), additional research should now be carried out on actual removal efficiencies of various organic contaminants by the accumulated carbon in a solids contact clarifier.

2. This research showed that the accumulation of powdered activated carbon is dependent on the carbon feedrates. Only two feedrates (10 mg/L and 25 mg/L) were used. Other feedrates, particularly on the higher side, should be investigated to determine the optimal accumulating rate. This will add to the operating information base on powdered activated carbon use in a solids contact slurry recirculating clarifier.

3. The entire powdered activated carbon feed exercise be carried out on a full scale solids contact slurry recirculating clarifier to confirm the rate of accumulation, distribution profile, and maximum powdered activated carbon concentrations attained on pilot scale clarifiers.

4. To quantify the benefits of powdered activated carbon use in a solids contact slurry recirculating clarifier, over its use in conventional clarifiers, a comparative study of a particular organic compound removal should be undertaken.

5. Any research on powdered activated carbon use in solids contact slurry recirculating clarifier should examine the influence on the adsorption capacity of the PAC in the slurry, due to the mean retention period of the PAC in the slurry and the exposure of background organics to the PAC.

6. If in the future the modified bottle point method, to determine chloroform isotherms for the slurries, is employed, the following modifications are recommended:

   (i) A minimum of three replicates for each slurry sample should be carried out including blank "organic free" samples.

   (ii) In addition to the replicates for each sample, a minimum of 4 or 5 points (3 points used in this research) be carried out to enable a better isotherm fit.

   (iii) Because of the volatile nature of chloroform and in view of each batch of the sample adsorption tests being carried out at four day intervals, the concentration of chloroform should be confirmed, through GC analysis, prior to use in each batch. The results should be accounted for in isotherm analysis.

   (iv) Due to exceedingly high concentration of chloroform in the samples, extreme care should be taken at all times and at all stages to minimize volatalization losses of chloroform.

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APPENDIX I

Sample Calculations

A.1.1 EXAMPLE CALCULATIONS FOR "MEAN RETENTION TIME"

EXPERIMENTAL RUN NO 3

OBS NO	EXP'T RUN HOURS	CARBON ADDED GRAMS	CUMULATIVE CARBON IN CLARIFIER GRAMS	CARBON DRAINED GRAMS	BALANCE IN CLARIFIER GRAMS	AVERAGE RETENTION TIME HOURS	MEAN RETENTION TIME HOURS
n	A	B	C	D	E	F *	G **
1	30	6750	6750	625	6125	15	15
2	66	8100	14225	661	13565	18	32.2
3	78	2700	16265	1216	15048	6	37.9
4	84	1350	16398	972	15427	3	40.5
5	96	2700	18127	0	18127	6	45.6
6	108	2700	20827	2199	18627	6	50.9
7	132	5400	24027	1726	22302	12	60.6
8	156	5400	27702	2403	25299	12	70.3
9	180	5400	30699	3306	27392	12	80
10	192	2700	30092	0	30092	6	83.9
11	204	2700	32792	3991	28801	6	88.4
12	228	5400	34201	2806	31396	12	96
13	235	1575	32971	2654	30316	35	98
14	286	11475	41791	4307	37484	255	115

** F(n) = (A(n)-A(n-1))/2* *** G(n) = ((G(n-1)+A(n)-A(n-1))E(n-1)+(B(n))F(n))/C(n)*

A.1.2 EXAMPLE CALCULATIONS FOR "BACKGROUND ORGANIC EXPOSURE FACTOR"

EXPERIMENTAL RUN NO 4 (CLARIFIER No. 1)

OBS NO	EXP'T RUN TIME (DAYS)	AVERAGE RIVER COLOR (TCU)	MEAN RETENTION TIME (HOURS)	BACKGROUND ORGANIC EXPOSURE (TCU.HR)	CARBON IN CLARIFIER (KILOGRAMS)	BACKGROUND ORGANIC EXPOS. FACTOR TCU.Hr/Kg
1	4	5	49	245	9.5	25.9
2	8	5	90	450	28.3	15.9
3	12	5	132	660	30	22
4	16	5	168	840	37	22.7
5	20	5	208	1020	27.6	36.9
6	24	60	9	540	2.75	196.7
7	28	25	14	350	4.4	79.5
8	32	20	12	240	3.82	62.9
9	36	15	32	480	10.3	46.7
10	40	10	53	530	17.1	31

A 1.3 EXAMPLE CALCULATIONS FOR TRACER STUDY PULSE INPUT

	CLARIFIER #2					ROMBERG INTEGRATION			
time	Ce	^t	tCe^t	Ce^t	tCe	I1(tCe)	I2(tCe)	I1(Ce)	I2(Ce)
0	0.00				0	-0.04	-0.08	-0.02	-0.02
2	-0.02	2	-0.08	-0.04	-0.04	-0.08		-0.03	
4	-0.01	2	-0.08	-0.02	-0.04	0.44	9.36	0.07	1.16
6	0.08	2	0.96	0.16	0.48	5.2		0.67	
8	0.59	2	9.44	1.18	4.72	23.22	88.64	2.44	7.78
10	1.85	2	37.00	3.70	18.5	58.1		5.15	
12	3.30	2	79.20	6.60	39.6	99.94	235.36	7.61	16.36
14	4.31	2	120.68	8.62	60.34	138.42		9.19	
16	4.88	2	156.16	9.76	78.08	172.94	359.76	10.15	19.94
18	5.27	2	189.72	10.54	94.86	196.66		10.36	
20	5.09	2	203.60	10.18	101.8	214.88	442.64	10.23	20.14
22	5.14	2	226.16	10.28	113.08	232.6		10.12	
24	4.98	2	239.04	9.96	119.52	247.96	505.6	9.92	19.48
26	4.94	2	256.88	9.88	128.44	261.72		9.7	
28	4.76	2	266.56	9.52	133.28	270.98	1000.58	9.35	31.92
30	4.59	2	275.40	9.18	137.7	725.75		22.375	
35	4.36	5	763.00	21.80	152.6	781.5	1600	20.9	40.4
40	4.00	5	800.00	20.00	160	818.5		19.3	
45	3.72	5	837.00	18.60	167.4	852.25	1708.75	17.975	34.45
50	3.47	5	867.50	17.35	173.5	869.625		16.6	
55	3.17	5	871.75	15.85	174.35	870.875	1759	15.175	29.5
60	2.90	5	870.00	14.50	174	878.625		14.075	
65	2.73	5	887.25	13.65	177.45	889.875	1791	13.2	25.7
70	2.55	5	892.50	12.75	178.5	898.125		12.4	
75	2.41	5	903.75	12.05	180.75	897.875	1775	11.6	22.3
80	2.23	5	892.00	11.15	178.4	881.625		10.7	
85	2.05	5	871.25	10.25	174.25	860.875	2544.375	9.85	27.75
90	1.89	5	850.50	9.45	170.1	1675.5		17.7	
100	1.65	10	1650.00	16.50	165	1584	3066	15.15	28.3
110	1.38	10	1518.00	13.80	151.8	1467		12.8	
120	1.18	10	1416.00	11.80	141.6	1332	2592	10.7	20.2
130	0.96	10	1248.00	9.60	124.8	1212		9	
140	0.84	10	1176.00	8.40	117.6	1150.5	2184	7.95	14.7
150	0.75	10	1125.00	7.50	112.5	1066.5		6.9	
160	0.63	10	1008.00	6.30	100.8	937.5	1836	5.7	10.5
170	0.51	10	867.00	5.10	86.7	847.5		4.65	
180	0.46	10	828.00	4.60	82.8				
			23203.14	360.5		23420.94	23497.98	369.81	370.9
						I(tCe) = 23395.25		I(Ce) = 369.426	

RESIDENCE TIME = 64.36 min (Rectangle rule)

RESIDENCE TIME = 63.33 min (Romberg method)

APPENDIX II

Isotherm Raw Data

A 2.1 ISOTHERM DATA - AVERAGE VALUES

AVERAGED Cf's

TIME	ORGANIC FREE Ci (ACTUAL) (ug/L)	ORGANIC FREE H20 Cf (ug/L)	ALMX SLUDGE Cf (ug/L)	2-C1 Cf (ug/L)	2-C2 Cf (ug/L)	2-C1 LOG (Cf)	2-C2 LOG (Cf)	2-C1 x/m (ug/g)	2-C2 x/m (ug/g)	2-C1 LOG (x/m)	2-C2 LOG (x/m)	2-C1 Carbon (mg/L)	2-C2 Carbon (mg/L)
4	1853	1229		5.9	17.9	0.77	1.25	634	1582	2.80	3.20	1927	765
4	2318	1763		7.6	28.4	0.88	1.45	911	2268	2.96	3.36	1927	765
4	2780	2651		8.2	31	0.91	1.49	1371	3425	3.14	3.53	1927	765
8	1853	1433	1727	4.17	17	0.62	1.23	455	1236	2.66	3.09	3138	1146
8	2318	1907	2201	11.25	24.45	1.05	1.39	604	1643	2.78	3.22	3138	1146
8	2780	1798	2715	5.95	33.75	0.77	1.53	571	1539	2.76	3.19	3138	1146
12	1853	1635	1442	5.4	16.0	0.73	1.20	488	1152	2.69	3.06	3337	1405
12	2318	1766	1396.5	13.7	24.4	1.14	1.39	525	1240	2.72	3.09	3337	1405
12	2780	1846	2019.5	8.9	24.3	0.95	1.39	551	1297	2.74	3.11	3337	1405
16	1853	1789	1736	4.1	8.6	0.61	0.93	434	1071	2.64	3.03	4113	1663
16	2318	2560	2325.5	6.0	10.8	0.78	1.03	621	1533	2.79	3.19	4113	1663
16	2780	2945	2979.5	8.2	19.2	0.91	1.28	715	1761	2.85	3.25	4113	1663
20	1853	1383		8	16.15	0.90	1.21	448	1005	2.65	3.00	3071	1360
20	2318	1764		10.7	17.4	1.03	1.24	571	1284	2.76	3.11	3071	1360
20	2780	1914		13.8	19.3	1.14	1.29	619	1393	2.79	3.14	3071	1360
24	1853	1536		128.6	459.0	2.11	2.66	4614	7804	3.66	3.89	305	135
24	2318	1806		188.0	705.0	2.27	2.85	5305	7978	3.72	3.90	305	138
24	2780	2051		247.0	885.0	2.39	2.95	5915	8449	3.77	3.93	305	138
28	1853	1536		53.05	132.5	1.72	2.12	3033	5179	3.48	3.71	489	271
28	2318	1806		76	186.65	1.88	2.27	3538	5975	3.55	3.78	489	271
28	2780	2051		98.85	236	1.99	2.37	3992	6697	3.60	3.83	489	271
32	1853	1217		50	278.95	1.70	2.45	2752	5071	3.44	3.71	424	185
32	2318	1869		133.1	420.8	2.12	2.62	4094	7828	3.61	3.89	424	185
32	2780	2349		160.8	506.5	2.21	2.70	5161	9959	3.71	4.00	424	185
36	1853	1256	1470	16.3	33.6	1.26	1.53	1085	1925	3.04	3.28	1141	635
36	2318	1804	1378	26.1	57.4	1.42	1.76	1558	2751	3.19	3.44	1141	635
36	2780	1976	1798	27.6	46.9	1.44	1.67	1708	3038	3.23	3.48	1141	635
40	1853	1550	1521	8.885	34.15	0.95	1.53	812	1822	2.91	3.26	1897	832
40	2318	1498	1532	11.4	35.7	1.06	1.55	784	1758	2.89	3.24	1897	832
40	2780	1926	2303	15.1	50.15	1.18	1.70	1007	2255	3.00	3.35	1897	832

A 2.2 ISOTHERM - RAW DATA

	FREE Cl (ACTUAL) (ug/L)	FREE H2O Cf (ug/L)	SLUDGE Cf (ug/L)	Cf (ug/L)	Cf (ug/L)	LOG (Cf)	LOG (Cf)	X/M (ug/g)	X/M (ug/g)	LOG (x/m)	LOG (x/m)	Carbon (mg/L)	Carbon (mg/L)
4	1853	1228		5.4	10.2	0.73	1.01	634	1592	2.80	3.20	1927	765
4	1853	1228		6.3	25.6	0.80	1.41	634	1572	2.80	3.20	1927	765
4	2318	1763		7.5	27.2	0.88	1.43	911	2269	2.96	3.36	1927	765
4	2318	1763		7.7	29.5	0.89	1.47	911	2266	2.96	3.36	1927	765
4	2780	2651		9.8	38.8	0.99	1.59	1371	3415	3.14	3.53	1927	765
4	2780	2651		8.6	28.2	0.93	1.45	1371	3428	3.14	3.54	1927	765
8	1853	1433	1701	3.7		0.57		455		2.66		3138	1146
8	1853	1433	1752	4.64	17	0.67	1.23	455	1236	2.66	3.09	3138	1146
8	2318	1907	2159	18.5	22.4	1.27	1.35	602	1645	2.78	3.22	3138	1146
8	2318	1907	2243	4.0	26.5	0.60	1.42	606	1641	2.78	3.22	3138	1146
8	2780	1798	2651	7.4	31.6	0.87	1.50	571	1541	2.76	3.19	3138	1146
8	2780	1798	2779	4.5	35.9	0.65	1.56	572	1538	2.76	3.19	3138	1146
12	1853	1635	1635	6.9	17.0	0.84	1.23	488	1152	2.69	3.06	3337	1405
12	1853	1635	1249	3.9	14.9	0.59	1.17	489	1153	2.69	3.06	3337	1405
12	2318	1766	1766	20.0	28.0	1.30	1.45	523	1237	2.72	3.09	3337	1405
12	2318	1766	1027	7.4	20.7	0.87	1.32	527	1242	2.72	3.09	3337	1405
12	2780	1846	1846	8.7	22.0	0.94	1.34	551	1298	2.74	3.11	3337	1405
12	2780	1846	2193	9.1	26.6	0.96	1.42	550	1295	2.74	3.11	3337	1405
16	1853	1789	1434	4.5	6.8	0.65	0.83	434	1072	2.64	3.03	4113	1663
16	1853	1789	2038	8	10.3	0.90	1.01	433	1070	2.64	3.03	4113	1663
16	2318	2560	2320	5.8	6.8	0.76	0.83	621	1535	2.79	3.19	4113	1663
16	2318	2560	2331	6.2	14.7	0.79	1.17	621	1531	2.79	3.18	4113	1663
16	2780	2948	2948	9.1	20.4	0.96	1.31	715	1760	2.85	3.25	4113	1663
16	2780	3011	3011	7.3	18.0	0.86	1.26	730	1800	2.86	3.26	4113	1663
20	1853	1383		8.6	19.6	0.93	1.29	448	1003	2.65	3.00	3071	1360
20	1853	1383		7.4	12.7	0.87	1.10	448	1008	2.65	3.00	3071	1360
20	2318	1764		10.2	25.2	1.01	1.40	571	1279	2.76	3.11	3071	1360
20	2318	1764		11.2	17.4	1.05	1.24	571	1284	2.76	3.11	3071	1360
20	2780	1914		14.2	13.5	1.15	1.13	619	1397	2.79	3.15	3071	1360
20	2780	1914		13.4	25.1	1.13	1.40	619	1389	2.79	3.14	3071	1360
24	1853	1536		123.0	459.0	2.09	2.66	4633	7804	3.67	3.89	305	138
24	1853	1536		134.2	352.5	2.13	2.55	4596	8576	3.66	3.93	305	138
24	2318	1806		188.0	715.0	2.27	2.85	5305	7906	3.72	3.90	305	138
24	2318	1806			695		2.84		8051		3.91	305	138
24	2780	2051		241.0	885.0	2.38	2.95	5934	8449	3.77	3.93	305	138
24	2780	2051		253.0		2.40		5895		3.77		305	138
28	1853	1536		52.6	122	1.72	2.09	3034	5218	3.48	3.72	489	271
28	1853	1536		53.5	143	1.73	2.16	3032	5140	3.48	3.71	489	271
28	2318	1806		74	208	1.87	2.32	3542	5897	3.55	3.77	489	271
28	2318	1806		78	165.3	1.89	2.22	3534	6054	3.55	3.78	489	271
28	2780	2051		102.6	254	2.01	2.40	3984	6631	3.60	3.82	489	271
28	2780	2051		95.1	218	1.98	2.34	4000	6764	3.60	3.83	489	271
32	1853	1017		50	277.4	1.70	2.44	2281	3998	3.36	3.60	424	185
32	1853	1017			280.5		2.45		3981		3.60	424	185
32	2318	1869		118.4	420.8	2.07	2.62	4129	7828	3.62	3.89	424	185
32	2318	1869		147.8		2.17		4059		3.61		424	185
32	2780	2349		160.8	495	2.21	2.69	5161	10022	3.71	4.00	424	185
32	2780	2349			518		2.71		9897		4.00	424	185
36	1853	1256		19.3	38.2	1.29	1.58	1084	1918	3.03	3.28	1141	635
36	1853	1256	1470	17.3	28.9	1.24	1.46	1086	1932	3.04	3.29	1141	635
36	2318	1804		33.2	55.8	1.52	1.75	1552	2753	3.19	3.44	1141	635
36	2318	1804	1378	26.1	58.9	1.42	1.77	1558	2748	3.19	3.44	1141	635
36	2780	1976	1758	27.1	55.2	1.43	1.74	1708	3025	3.23	3.48	1141	635
36	2780	1976	1838	28.0	38.5	1.45	1.59	1707	3051	3.23	3.48	1141	635
40	1853	1550		6.8	36.6	0.83	1.56	813	1819	2.91	3.26	1897	832
40	1853	1550	1521	10.97	31.7	1.04	1.50	811	1825	2.91	3.26	1897	832
40	2318	1498	1279	11.1	55.8	1.05	1.75	784	1733	2.89	3.24	1897	832

APPENDIX III

Pilot Plant Details

Methodology

Development of the Mobile Water Treatment Plant

Due to the site specific nature of many water problems and the alterations of water characteristics with sampling, transport and storage, a heavy emphasis was placed on the development of field or on-site research capability. To encompass various applications, a plant was designed to provide optimum flexibility. The incorporation of alternative technologies into a facility based on conventional treatment (Class 4) provides the ability to subject source waters to a wide variety of treatment options. This versatility provides the greatest potential of arriving at the optimum solution for any given situation. This approach was intended to provide a facility with a continuing useful life thereby spreading the initial investment dollars over a long period of application. The additional advantage of this approach is the capability of rapid configuration of the pilot plant to meet specific requirements at the Alberta Environmental Centre. When ready, it is simply moved to the study site of interest.

A comparison of initial capital costs showed only a small difference between 136 Lpm (30 gpm) and the 227 Lpm (50 gpm) capacities with the overall weight and dimensions increasing slightly. A 341 Lpm (75 gpm) plant, however, was significantly more expensive and the overall weight of the components nearly doubled. A capacity smaller than 100 Lpm would have required custom built components, making its costs similar to that of a 227 Lpm (50 gpm) plant. Also, this small a plant would have a considerable scale-up factor to full municipal sizing. Consequently, the system was tailored around a nominal capacity of 227 Lpm (50 gpm).

With the selection of the 227 Lpm (50 gpm) plant capacity, the prospective shelter for the components was designed to provide the optimum accommodation for the selected water treatment plant. This plant consists of 2 reactor-clarifiers, 2 filters and a collection reservoir, whose heights normally run about 2.44 m (8') to 3.05 m (10'). The size of the shelter which proved most feasible was 3.66 m (12') wide by 15.85 m (52') long with an overall maximum outer height of 4.75 m (15' 7"). There is a 0.305 m (1') overhang on both sides of the lowboy, but this does not cause any instability since the significant loadings were located along the trailer's centreline.

The initial goal was to select a self-contained trailer with axles and wheels intact. Although the floor area needed for this type of shelter was commonly available, the static weight support and minimum inner height requirements of our treatment plant dictated that our trailer would have to be custom built. Upon notifying several trailer manufacturers concerning our requirements, it was learned that the height could be adjusted but no standard tandem-axle support was available to withstand the 45.41 tonne (50 ton) static load. [Dyramic load = 15.0 tonnes (16.5 tons)].

The obvious solution to the weight problem was to purchase both a lowboy trailer base and a trailer shelter mount. The static weight was primarily supported by the lowboy's frame and an additional three pairs of heavy duty dolly legs. The deck size selected for the lowboy was 3.05 m (10') wide by 15.85 m (52') sitting 1.07 m (42") from deck-top to ground level to conserve height. Since most lowboys of tandem (dual-rear axle) structure are built to be 2.59 m (8.5') wide, the 3.05 m (10') width needed was specially built. This was preferable over building the lowboy to be 3.66 m (12') wide (like the trailer body), since the 3.05 m (10') width is easier to drive, and the rear axles for the 3.66 m (12') trailer would have to be excessively elongated, decreasing their durability and carrying capacity.

To ensure compatibility with municipal plants, specifications were prepared for a range of flow conditions for both clarifiers (Table 2) and filters (Table 3). The final layout of the plant is given in Figure 1.

The versatility in water treatment was increased by the insertion of extensive interconnecting piping and flow control valves. The plant contains two reactor clarifiers and two filters, so interconnecting plumbing allows the clarifiers and filters to operate in series, in parallel, or as independent clarifier-filter systems operating side by side at different chemical dosages/flow rates (Figure 2). Clarification times and chemical dosages can therefore be modified to suit different water inlet sources. This highly adaptable unit actually simulates many different water treatment plants but at a fraction of the cost.

Ease of operation was increased with the addition of a microprocessor which remotely controls and monitors the output parameters. This permitted the option of running the plant unmanned for extended periods of time providing that the chemical additives are provided for. A 36 to 48 channel input microprocessor which would monitor and record signals from pumps, thermocouples, turbidimeters, colourimeters, hardness testers, pH meters, flowmeters, chlorine meters, chlorine dioxide, conductivity meters, and chemical feed equipment was therefore built in.

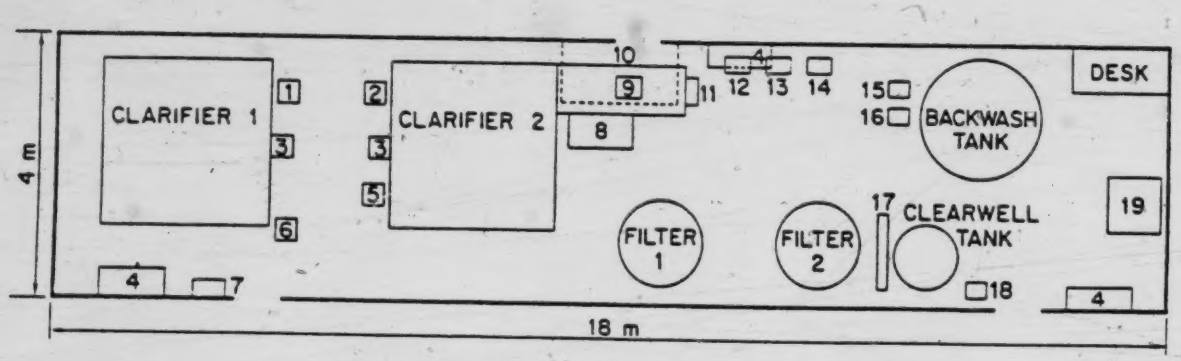
Table 2. Operating specifications for each clarifier.

Potable Output		Rise Rate Under Troughs		Retention Time to Overflow
LPM	IGPM	LPM/M^2	GPM/FT^2	MINUTES
45.50	10.0	14.70	0.30	250.0
91.00	20.0	29.40	0.60	125.0
113.75	25.0	36.75	0.75	100.0
136.50	30.0	44.10	0.90	83.3
182.00	40.0	58.80	1.20	62.5
227.50	50.0	73.50	1.56	50.0

Table 3. Operating specifications for each filter:

Potable Output		Operation Rate	
LPM	IGPM	LPM/M^2	GPM/FT^2
45.50	10.0	32.81	0.67
91.00	20.0	65.13	1.33
113.75	25.0	97.94	2.00
136.50	30.0	130.75	2.67
182.00	40.0	163.07	3.33
225.50	50.0	195.88	4.00

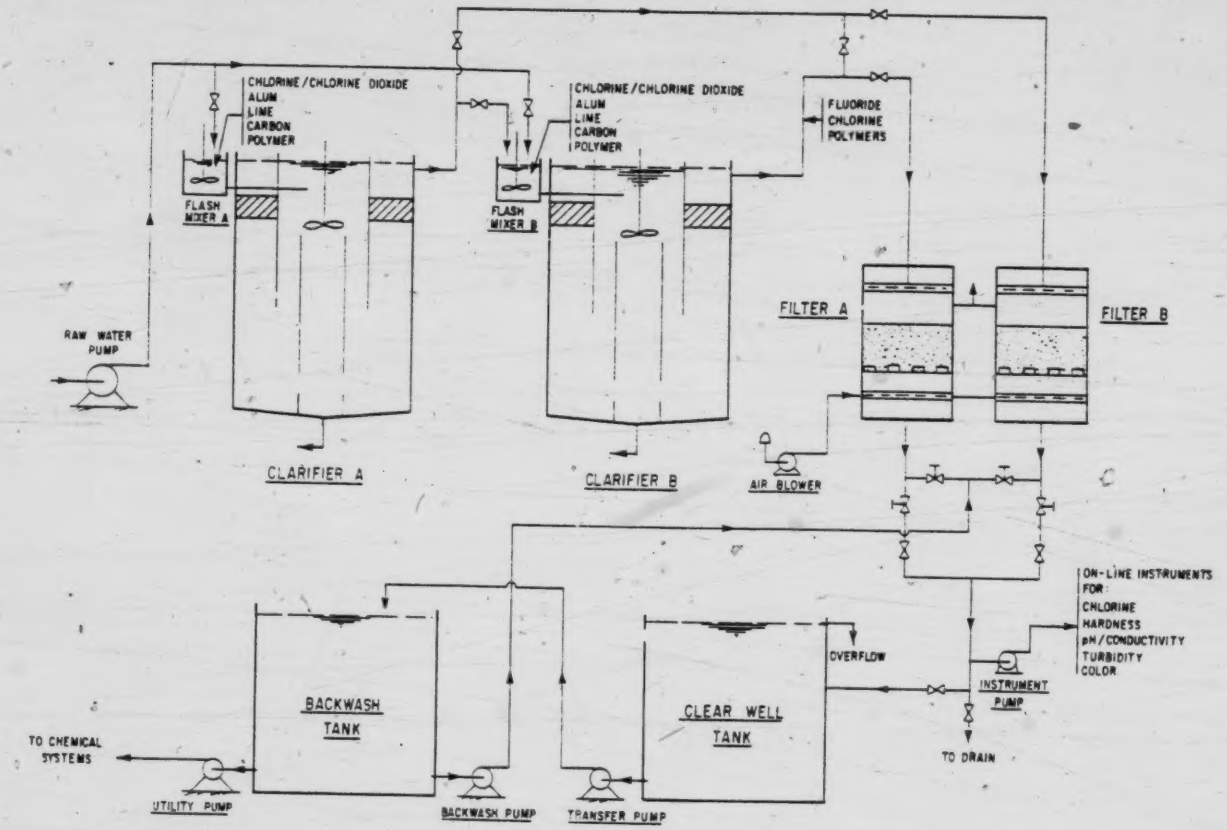
Figure 1. Layout of mobile water treatment plant.



LEGEND

1. ALUM FEED
2. LIME FEED
3. RAPID MIX CHAMBERS
4. HEATERS
5. CARBON FEED
6. POLYMER FEED
7. CHLORINE DIOXIDE SYSTEM
8. CONTROL PANEL
9. AIR BLOWER
10. CHLORINE ROOM
11. TURBIDIMETER
12. TOTAL CHLORINE ANALYZER
13. HARDNESS ANALYZER
14. FREE CHLORINE ANALYZER
15. BACKWASH PUMP
16. UTILITY PUMP
17. POTABLE WATER METERING PROBES
    (pH , conductivity , temperature , photometric analyzer)
18. TRANSFER PUMP
19. COMPUTER CONTROL SYSTEM

Figure 2. Flow schematic for mobile water treatment plant.



W3026

PLANT DESCRIPTION

M W T P

INTRODUCTION

The trailer-mounted, mobile water treatment pilot plant was constructed by Petwa Canada Ltd., Calgary, Alberta for the Alberta Environmental Centre, Vegreville, Alberta.

The treatment components include chemical addition, flocculation, sedimentation and filtration for the removal of contaminants from a variety of raw water supplies.

The system can be operated in several ways to determine the optimum treatment method for a particular water supply.

Following is a brief description of the various components of the system:

RAW WATER FEED PUMPS

Two raw water feed pumps are supplied which lift the water from the source to the plant. These are Viking 540 Model 1-1A pumps each with a capacity of 50 USGPM at a total dynamic head of approximately 210 feet.

Each pump is mounted on a wooden platform with a cover for weather protection, and carrying handles.

A 100-foot length of 2 1/2" non-collapsible suction hose with foot valve/strainer is supplied with each pump. Also, one

200-foot length and one 300-foot length of 2" discharge hose is included. Connectors on the hoses are Kam-Lok fittings.

CLARIFIERS

The two clarifiers are 7 ft X 7 ft X 8 ft high, each with a capacity of 50 USGPM and include the following:

1. Chemical injection points
   Five valved injection points are installed on the inlet line to each clarifier. Chemical feed systems can be connected as required depending on the treatment processes being tested.

2. Flash mixers (rapid mix chamber)
   A flash mix chamber, 12" X 12" X 30", is installed on the side of each clarifier to provide intimate contact between the chemicals and the raw water. The flash mixers are Eastern variable speed units.

3. Flocculator
   The flocculation chamber consists of a steel shell 4'6" X 4'6" X 5'0"high (see drawings for alternate arrangement). The flocculator itself consists of an 18" diameter draft tube and a turbine which, as it rotates, draws sludge up the draft tube and into the flocculation zone to contact the incoming solution from the flash mix chamber. The variable speed turbine drive consists of a Model 456 hub city reducer with 1 HP motor, MAC100 AC adjustable speed controls and WR0040 Morse remote control.

4. Scraper mechanism
   The sludge which settles to the floor of the clarifier is

continuously scraped into the hopper. The scraper drive consists of a 3801 hub city double reduction reducer with 1/2 HP motor. Scraper speed can be altered by changing sprockets on the drive system.

5. Sludge pumps

The two sludge pumps are Ramoy Model 34401 with 1/4 HP motors and variable speed drives. The piping and valving arrangement is such that the sludge can be disposed of to the drain and/or recycled to the clarifier inlet.

6. Settling tubes

The 60° plastic settling tubes can be utilized to increase the capacity of the clarifiers. Please note that settling tubes cannot be used with the alternate flared flocculation compartment arrangement.

GRAVITY FILTERS

The two gravity filters are 4 ft diameter X 8 ft high. Each filter is rated at approximately 50 USGPM depending on filter media utilized. Following are the components of the filtration system:

1. Distributors and collectors

The outlet collector and air distributor are PVC header/lateral systems to evenly distribute and collect water and air over the entire filter bed area.

2. Control valves

The automatic valves are Aqua-Matic plastic diaphragm valves, pneumatically-operated, with 4-way solenoid valves

which are operated by the central control system.

3. Air compressor

The air for control valve operation is supplied by a Scott compressor with receiver tank.

4. Backwash initiation

A mercury level switch installed in each filter automatically initiates the backwash through the control system when the head loss in the filter reaches the predetermined setting.

5. Filter media

The media used for filtration will depend on the treatment processes being tested.

6. Air blower

Prior to backwashing with water, an air scour system is included to loosen materials from the media bed. The air blower is a Sutorbilt Model 3 HVF with 3 HP motor with a capacity of 40 SCFM at 7 psi.

7. Backwash system

The backwash tank is a 6 ft diameter X 9 ft high fiberglass tank with capacity to provide sufficient filtered water for backwashing at least one of the filters.

The backwash pump is a Jacuzzi Model 3 DM 1 1/2-T208 with 5" impeller and 3 HP motor.

CLEARWELL TANK

The clearwell tank receives filtered water from the filters and is a 3 ft diameter by 6 ft high fiberglass vessel.

TRANSFER PUMP

This pump transfers filtered water from the clearwell tank to the backwash tank. The pump is a Monarch Model BVE-50 with a 1/2 HP motor and a capacity of 70 USGPM at 15 ft T.D.H. The operation of this pump is controlled by the level in the clearwell tank.

BACKWASH TANK

This is a fiberglass tank, 6 ft diameter X 9 ft high, in which the treated water is stored for filter backwashing and utility purposes. Any excess water which enters the tank overflows to drain.

UTILITY PUMP

The utility pump is a Jacuzzi Model 5C-RJ2-S which provides treated water for mixing chemicals, chlorine gas dilution, chlorine dioxide dilution, cleaning and any other uses that may arise. This pump is equipped with a pressure tank and operates automatically on demand through a pressure switch.

CHEMICAL TREATMENT EQUIPMENT

As this is a pilot plant, equipment has been included to inject several chemicals at various points throughout the system. Following is a brief description of each chemical feed system:

1. Alum

   Alum is used to coagulate suspended solids and colour to facilitate removal in the clarifier.

   The feed system consists of an Accu-rate Model 602 variable speed dry volumetric feeder with storage hopper. This feeder discharges into a small tank where the powder is dissolved in water.

   A mechanical agitator ensures an even solids content throughout the tank. A float valve maintains the slurry at a constant level in the tank.

   The solution feeder is a Wallace and Tiernan 94 Series metering pump. The feed rate is manually adjustable.

2. Lime

   Lime is used to reduce the hardness level by aiding in the precipitation of calcium and magnesium compounds.

   The feed system is the same as the alum system previously described, except that a slurry metering pump is utilized.

3. Powdered activated carbon

   Activated carbon adsorbs organic materials which produce colour, taste and odour problems in a water supply. The exhausted carbon is removed in the clarifier and/or filter.

The feed system is also as described for the alum feed, except that a slurry metering pump is utilized.

A duct fan is installed above the carbon hopper to evacuate powder during loading of the hopper.

4. Polymer

Various polymers can be used to aid in the coagulation and flocculation of contaminent particles. The polymer feed system is a Stranco Model PB-2. The neat liquid polymer is withdrawn from the polymer drum, wetted and mixed into a solution, which is then injected by the manually adjustable metering pump.

5. Chlorine

Chlorine is used for disinfection purposes, as well as for the oxidation of various contaminants. The chlorination system is a Fischer & Porter Model 70C1710C with an automatic switchover system so that when one chlorine cylinder exhausts, the spare automatically comes on stream.

With this system it is possible to inject the chlorine solution to two points at the same time independently at manually adjustable rates.

Also included is a Wallace & Tiernan 50.125 chlorine gas leak detector with an alarm to indicate gas leaks.

The gas chlorination system is housed in a separate room with outside access as required by safety regulations.

6. Chlorine Dioxide

Chlorine dioxide is a very strong oxidant used generally for the same purposes as chlorine.

The system is a Prominent CD-120 unit which utilizes dilute hydrochloric acid and dilute sodium chlorite solutions for the generation of chlorine dioxide. The feed rate is manually adjustable.

7. Sodium Fluoride

Sodium fluoride is used to increase the fluoride level in domestic water supplies.

The system includes a Wallace & Tiernan Series 47.050 NaF saturator with manually adjustable A-588 solution metering pump.

A Petwa water softener is also included on the water supply line to the NaF saturator to prevent solids deposition in the saturator tank.

WATER QUALITY MONITORING EQUIPMENT

Several analyzers and monitors have been included to provide continuous readings of various water quality parameters. A brief description of each item follows:

1. pH

Two pH monitors with probes provide a continuous indication of the raw water and treated water pH.

The monitors are Prominent Model PHS 014 K2 507 and are mounted in the meter panel between the filters. The probes are mounted on the raw water inlet and clearwell inlet.

2. Temperature

Four RTD's (resistance temperature detectors) are installed in thermowells at various points throughout the system to provide continuous temperature monitoring.

The temperature indicators consist of thermowells, 100 ohm platinum RD's and Mescon #110-2 wire RTD transmitters.

3. Conductivity

A conductivity monitor provides a continuous indication of the conductivity of the treated water.

The system consists of a Prominent Model LFS-2000 K2 monitor with type LDT probe.

4. Turbidity

A continuous turbidity indication of the filtered water is provided by a Hach Ratio 2000 Turbidimeter, which is supplied with a continuous sample from the filtered water line.

5. Hardness

The treated water hardness is continuously monitored by a Hach Model 61600-03 pump-colorimeter analyzer which is also supplied with a continuous sample from the inlet to the

As the maximum hardness limit for this analyzer is 50 mg/l, a sample dilution system has been incorporated to provide a 10:1 dilution of the sample and increase the detection range to 0-500 mg/l.

The dilution water is obtained from the water softener to ensure zero hardness.

The flow of dilution and sample water through the rotameters provided must be adjusted to provide the 10:1 dilution.

6. Free & Total Chlorine

The free and total chlorine residuals are continuously monitored by Hach Model 61100-01 and Model 31300-03 pump-colorimeter analyzers respectively.

These analyzers are also supplied with a sample from the clearwell inlet on a continuous basis, but unlike the hardness analyzer, do not require a sample dilution system.

N.B.: Samples for the tubidimeter and pump-colorimeter analyzers are supplied under pressure by a Little Giant centrifugal pump.

7. Colour

A Model 450/34 Monitek in-line photometric analyzer continuously measures the colour of the treated water.

FLOW MEASURING EQUIPMENT

Following is a list of flow indicators in the system:

1. Raw water flow to Clarifier A

   This is a Fischer & Porter Model 10D1475AJBC11BAB magnetic flow meter which provides a continuous flow indication to the control system. Also included is a Universal indicating totalizer Model 52FT1210ABB.

2. Raw water flow to Clarifier B

   This is a Blue & White rotameter Model CF30 200 P which provides a visual indication of flow.

3. Filtered water flow from filter A

   This is a Signet MK515 flosensor with MK 579 flow rate indicator.

4. Filtered water flow from filter B

   This is a Fischer & Porter magnetic flow meter indentical to 1. above.

5. Backwash flow

   This is a Blue & white rotameter Model CF30 200 P which provides visual indication of the backwash rate to the filters.

LEVEL SWITCHES

Mercury type level switches are installed in the various tanks to perform the following functions:

1. Filters A & B

   - high level - to initiate backwash

2. Clearwell tank
   - high level - start transfer pump
   - low level - stop transfer pump
   - low low level - stop transfer pump to prevent it from running dry

3. Backwash tank
   - low low level - stop backwash and/or utility pumps to prevent them from running dry.

CONTROL SYSTEM

The central control system is a Fischer & Porter Micro-DCI rack-mounted assembly Model 53RM1151A and consists of the following components:

1. 19-inch rack
2. supervisor Model 53SU1000
3. five (5) chameleon microcomputer Mark II Model 50KM2000
4. CRT
5. operator's keyboard
6. engineering keyboard
7. disk drive
8. printer Model LA-50

Also supplied is a Columbia VP computer with dual disk drive, 128K RAM, amber monitor and software package.

MOTOR CONTROL CENTRE

The MCC contains starters, relays, etc. for the various motors in the plant with switches to allow manual operation and equipment isolation.

Water treatment research system in place

This 50-foot long mobile water research unit is used in the Centre's potable water technology research and development program. The unit contains a complete drinking water treatment plant allowing on-site studies of drinking water treatment problems. Most recently, the research facility has been used in studies on the treatment required for the control of giardiasis in drinking water.

A fully-equipped analytical laboratory is used in support of projects in the potable water research and development program. A smaller mobile analytical laboratory and a mobile treatment plant complete with ozone treatment capability are also used in the drinking water studies.

Researchers at the Centre are trying to find better ways of treating the province's drinking water.

They are undertaking broad-ranging research into drinking water treatment technology aimed at solving problems as diverse as iron in farm wells and "beaver fever" organisms in municipal drinking water.

Emphasizing on-site research, the Centre is assessing current and new water treatment technology and developing new approaches to treating water for human consumption.

The program addressing these concerns is the Centre's "Potable Water Technology Research and Development Program" managed by Dr. Albert van Roodselaar. Recent conference presentations by Drs. van Roodselaar and M. Wilson (Western Canada Water and Sewage Conference in Calgary and the World Congress III of Chemical Engineering in Tokyo, Japan) outlined drinking water problems in the province and steps the Centre is taking to study and solve them.

Many treatment problems arise from the characteristics of the source water, resulting in distinctly different treatment requirements in different locations. For example, some communities periodically experience foul-tasting and smelling water during spring runoff. In other instances, cool, clean mountain water sources may harbor the organism that causes giardiasis, or "beaver fever". There may also be problems in treating water that receives effluents from industries. As well, people who get their drinking water from underground sources face traditional problems such as high iron and dissolved salt levels, in addition to the newer problem of potential groundwater contamination.

> On-site investigations are emphasized.

Dr. van Roodselaar states that the high proportion of people living outside Alberta's major cities imposes some particular demands on the Alberta research program. Around 20 per cent of Albertans have their water treated in small municipal plants. Smaller centres often lack the manpower to ensure ideal treatment plant operation.

The research program was developed around these problems. An on-site investigation of problems was emphasized because water treatment needs vary from place to place and because the characteristics of water can change if it is transported to a central test facility for study.

To carry out the on-site studies, two main mobile facilities were developed. The first is a demonstration-scale mobile treatment plant which can treat 200 litres of water per minute. This unit has all the operating components of typical municipal treatment plants. The 50-foot self-contained trailer can be moved to locations where appropriate processes can be evaluated. This unit can also be used to demonstrate water treatment processes and for training plant operators.

The second facility is a smaller mobile trailer capable of treating eight litres of water per minute. It was acquired for research at sites with lower water flow and for situations where ease of relocation is important. In addition to traditional water treatment processes, the trailer has an ozonation unit, allowing ozonation of water, a potential alternative to chlorination in some circumstances.

Support for these portable research units and for laboratory research is provided by a specialized analytical laboratory located in the main Centre complex in Vegreville. A mobile field laboratory has also been developed as an extension to this laboratory.

Currently, the drinking water treatment research is concentrating on the removal or inactivation of giardia cysts in drinking water. In co-operation with the University of Calgary, the larger research unit is being used to evaluate various types of treatment to control the organism. Information is being generated which may lead to effective treatment standards for communities susceptible to waterborne "beaver fever" outbreaks.

The demonstration-scale research plant will also be used to study technology for removing color from water which receives effluent from pulp mills. In addition, plans are being developed for studies in small communities where color, taste and odor are treatment problems.

Another project is being developed to assist farmers, acreage owners and others who rely on wells for their water. Alberta Agriculture has undertaken preliminary tests on well chlorination, small-scale reverse osmosis and iron removal treatment systems.

On a larger scale, preliminary work has been started on a study of the possibility of removing iron from groundwater sources before the water is removed from the ground.

A major long-term objective of the research is to improve monitoring and process control technology for treatment plants. Automatic control of treatment plant operations would be of particular benefit to plants in small communities where manpower is often a problem.

CENTRE REPORT

Alberta Environmental Centre, Vegreville ISSN 0824-85X Vol. 1, No. 2 Summer 1985

Water treatment plant is delivered

The Centre's new mobile water treatment plant is being tuned up for excursions to communities and areas across Alberta where drinking water treatment problems occur.

The 50-foot long, 15-ton white trailer was delivered to the Vegreville laboratory in March following its construction by an Alberta firm.

After a period of 'debugging' on site, the plant will be moved to locations in Alberta where treatment problems are occurring as a result of factors ranging from industrial effluents to biological concerns to naturally high contaminant levels in water.

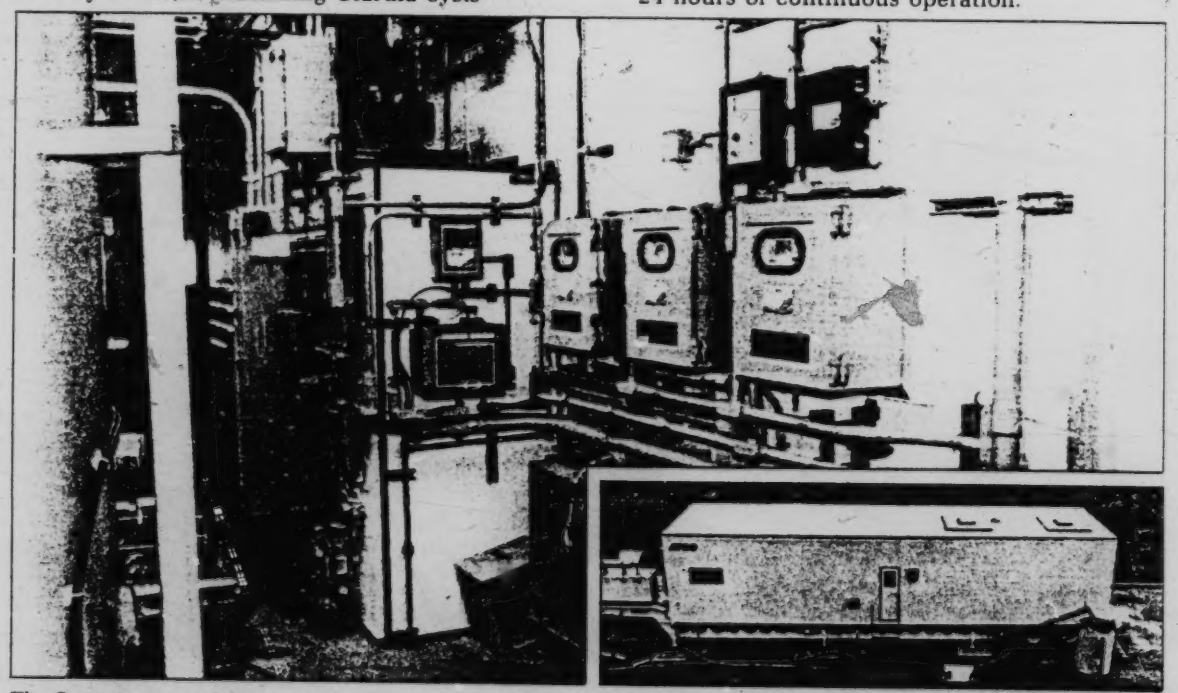
Dr. Albert van Roodselaar, in charge of the project, says the plant will collect information to determine how effluents and other substances affect municipal treatment systems. Towns and cities will be able to use this information in planning and operating their treatment facilities.

The unit can also provide an emergency water treatment capacity sufficient to alleviate water problems in towns of 2,000 to 10,000 people. One of the first projects planned will evaluate the treatability of water containing Giardia cysts ("beaver fever") by conventional plants.

The treatment plant has a capacity of 200 litres per minute. This was determined to be the smallest municipally-adaptable plant which incorporated industrial class components and favorable capital and operating costs. Design of the facility also required careful consideration of overall weight and size because of highway transit regulations.

The unit's treatment capability includes flocculant clarification, softening, regular media filtration, carbon filtration and disinfection with chlorine or chlorine dioxide. Provision has also been made for the addition of ozone treatment. It contains equipment for monitoring various parameters including turbidity, hardness, pH and free and combined chlorine.

Since the unit will often be located in remote areas, it is self-powered and has its own pressurized water system, a complete data storage system and automatic controls. It also contains sufficient fuel and chemical storage for 24 hours of continuous operation.



The Centre's new mobile water treatment research plant is equipped to assess drinking water needs throughout Alberta.

Alberta ENVIRONMENTAL CENTRE

APPENDIX IV

Study Progress Meeting Minutes

PAC PILOT PLANT STUDY
STEERING COMMITTEE MEETING NO.1

Oct. 27, 1987 14:30 Hours

PRESENT:	A. Van Roodselaar	- Alberta Environmental Centre (AEC)
	P. Huck	- University of Alberta
	D. Murdoch	- City of Edmonton
	K. Kassam	- City of Edmonton

COPIES TO:	All Present	E. Doyle
	L. Jenkins	W. Howe
	B. Gray	

1.00 General Discussion

A general discussion on the direction of the study was held. K. Kassam shared some of his discussions held with V. Snoeyink. P. Huck reviewed V. Snoeyink's proposal on PAC project. The discussion concluded on the following objective for the study:

1) Investigate the accumulation of PAC in slurry recirculating clarifier.
2) Carry out bench scale isotherm derivations at various stages of the experiment with respect to a specific contaminent. Chloroform would be a preferred compound due to a good basis of information on it. A second contaminant (site specific) may be considered.
3) Time permitting Plant (Pilot) scale spiking of this contaminent to compare clarifier performance.

1.01 Start-Up

During discussion, it was felt that planning and scope of experiment could have time constraints and start-up and commissioning of the pilot plant could prove to be a limiting factor depending on start-up time requirements. Also, the general philosophy of operating two parallel streams with one used for control is dependent on the comparative behaviour of the two clarifiers. The following schedule was developed:

Activity	Action	Date
PLANT DELIVERY ON-SITE	A.Van Roodselaar	Nov. 9, 1987
HOOK-UP Power Water Heat, etc.	K. Kassam (Through E.L. Smith Maintenance)	Nov.9-30, 1987
INITIAL START-UP	K.Kassam / B.Gray	Dec.1-30, 1987

1.20 Pilot Plant Commitments

Concern was expressed on the duration of plant loan for the purpose of completing the project. The initial six month may not be sufficient. A. Van Roodselaar did agree to extending the term if need be to fall 1988. He will follow up on this with a letter to the City.

ACTION: A. Van Roodselaar

1.03 Analytical Procedures

The exact procedure for determining carbon accumulated in the sludge blanket still needs to be developed. The use of acid dissolution or volatilization were suggested. Concern with respect to suspended matter in raw water should be considered when during development. It was agreed that Frank Skinner, Chemist for AEC, could develop this with assistance from two students proposed to be hired under the government winter subsidy program by City and AEC. The actual analysis would be carried out by the students on site under direction of K. Kassam.

ACTION: A. Van Roodselaar / K. Kassam

1.04 Isotherm Derivations

The proposed bench scale isotherm derivations will have to be carried out by one of two ways. Either through an M.Eng. student or through contract to the University of Alberta. Cost estimate on doing these can only be determined after the exact scope of work is finalised. This will be done by next meeting after the start-up of the Plant.

ACTION: Steering Committee

1.05 Additional Analysis

A. Van Roodselaar stated that AEC would be prepared to carry out GC/MS analysis on spiking results. In addition, during isotherm derivations examine the amount of adsorption of contaminent by carbon. The steering committee will decide this by next meeting.

ACTION: Steering Committee

1.06 Experimental Plan

On the basis of successful start-up of the pilot plant, the following general experimental plan was to be followed:

1) Compare similarity in characteristics of the two clarifiers using effluent turbidity and blanket solids concentration as criteria. Also vary variables, i.e. chemical dose, blanket depth, solids concentration to confirm similarity.
2) Commence feeding carbon to one unit and nothing into the second (control) unit. Compare carbon accumulation between first and second unit. Also turbidity performance with control unit. Conduct isotherm studies at various stages of the experiment.
3) Compare slow versus fast feed of carbon and its effects on accumulation in clarifier blanket. Again conduct isotherms at various stages.
4) If time permits, spike the two clarifiers with an organic compound and compare performance between two clarifiers and isotherms observations.

1.07 Selection of Contaminent Compounds

A discussion on the selection of compounds for removal through carbon adsorption (spiking and isotherm) was still to be finalised. P. Huck suggested the use of chloroform as one compound but said the following criteria be used to select a second:

i) Analytical capability
ii) Basic data (literature, isotherm info.)
iii) Relevance to E.L. Smith Plant

The steering committee to decide on this at subsequent meetings.

ACTION: Steering Committee

1.08 Schedule

A schedule to target a completion of all activities as discussed was to be put together by K. Kassam and included in the minutes of this meeting.

ACTION: K. Kassam

1.09 Rental Fee

This item was discussed after the meeting between A. Van Roodselaar and K. Kassam. The City had agreed to pay AEC the sum of $10,000 towards rental of the pilot plant trailer for a period of six months. AEC had supplied the City with a list of material in amount of $10,000 to be procured by the City to fulfill its requirements for rental fee. K. Kassam to coordinate purchase with B. Gray and confirm this in writing with A. Van Roodselaar.

ACTION: K. Kassam

1.10 Adjournment

The meeting was adjourned at 1700 hours. The next meeting will be held at 1400 hours on Thursday, December 10, 1987 at the E.L. Smith Plant.

PAC PILOT PLANT STUDIES

PROPOSED SCHEDULE OF ACTIVITIES

NO.	ACTIVITY	NOV 87	DEC 87	JAN 88	FEB 88	MAR 88	APR 88	MAY 88	JUNE 88	JULY 88	AUG 88
1	Pilot Plant Arrival and Hook-up	****									
2	Commission Plant		****								
3	Develop Carbon Analysis Procedure	**	****								
4	Experiment 1			****							
5	Experiment 2				***						
6	Experiment 3				*	**					
7	Experiment Spring Runoff					**	**				
8	Experiment Spikes						**	*			
9	Lab Analysis Isotherms/Carbon				****	****	****	**			
10	Data Analysis							**	**		
11	Report Preparation								**	****	****
12	Thesis Submittal										↓
13	Steering Committee Meetings		*	*	*	*	*	*	*		*

* Each star represents one week

PAC PILOT PLANT STUDY
STEERING COMMITTEE MEETING NO.2

DEC. 10, 1987 14:00 Hours

PRESENT:	A. Van Roodselaar	- Alberta Environmental Centre (AEC)
	P. Huck	- University of Alberta
	D. Murdoch	- City of Edmonton (Water Treatment)
	K. Kassam	- City of Edmonton (Water Treatment)
	D. Poole	- City of Edmonton (P.D.T.)

COPIES TO:	All Present	B. Gray
	A. Davies	R. Shariff

2.00 Review of Previous Meeting Minutes

1.00 Study Objectives

D. Murdoch pointed out that the objectives set out at the last meeting were not clear and proposed a revision . The committee agreed to the following objectives:

1) Establish the means of creating one or more stable and reproducible level of PAC accumulation in a slurry recirculatory clarifier blanket using a pilot scale mobile water treatment plant.

2) Conduct bench scale isotherm derivations using accumulated carbon at various stages of the experiment with respect to a specific contaminent to determine the "residual" adsorption capacity of the carbon.

3) Time permitting Plant (Pilot) scale spiking of the selected contaminent to compare clarifier performance.

1.01 Start-Up Schedule

The proposed schedule was reviewed. The water hook up was not carried out by November 30 as planned but is now complete for start up December 15th, 1987. K. Kassam to revise the schedule to reflect the delays.

ACTION: K. Kassam

1.02 Pilot Plant Commitments

A. Van Roodselaar to write memo to confirm the period of the study and availability of the plant for this purpose.

ACTION: A. Van Roodselaar

1.03 Analytical Procedures

A. Van Roodselaar (AVR) reported that Frank Skinner from Alberta Environmental Centre had commenced work on the analytical procedure to determine carbon (PAC) in the sludge. K. Kassam had supplied separate samples of sludge and carbon (see Attachment). Some difficulties had been experienced with respect to the procedure:

1) Not all sludge seemed to have dissolved during acidizing.

2) The use of paper filters was not possible at low pH.

3) Use of glass filters would cause a problem in the muffle furnace.

The results obtained showed about 15% accuracy.

P. Huck however, pointed out various other factors that could be contributing and suggested some options (see Attachment). On the basis on the discussion it was agreed that monitoring of Total Organic Carbon (TOC) in influent and Dissolved Organic Carbon (DOC) in effluent would help in the overall mass balance. P. Huck agreed to do some analysis of DOC and TOC at the University. AVR to follow up in modifying the procedure. K. Kassam to run initial trials and supply samples to do some preliminary analysis on quantifying PAC in sludge. Also K. Kassam to provide P. Huck with TOC and DOC samples.

ACTION: A. Van Roodselaar / K. Kassam / P. Huck

1.04 Isotherm Derivations

P. Huck provided an estimate of $1,000 per set of isotherm. At least 2 sets and maybe 3 may be required. D. Murdoch pointed out that there were no funds in the budget for this and alternate means should be looked into. It was decided that a plan for isotherm requirements be put together once the plant is up and running.

ACTION: K. Kassam

1.05 Additional Analysis

The committee has put the plans for determining amount of contaminent absorbed by carbon through GC/MS analysis on hold until A.V.R. reports back on the procedure. The spiking analysis in clarifier performance will still be carried out by Alberta Environmental Centre.

ACTION: A. Van Roodselaar

1.07 Selection of Contaminent Compounds

It was decided that just one contaminent "chloroform" will be used for spiking and isotherm purpose because of its universal concern and also information and analytical technique data available.

CLOSED

1.09 Pilot Plant Equipment

Various equipment for pilot plant use, worth $10,000, had been ordered by the City. The purchase is the city's contribution to the project. K. Kassam will update when all ordered equipment is received.

ACTION: K. Kassam

2.01 NEW BUSINESS

2.02 Plan and Budget

D. Murdoch proposed that K. Kassam come up with a definite plan of experiment and proposed costs involved on the project. This will be supplied at the next meeting.

ACTION: K. Kassam

2.03 Tour of Facility

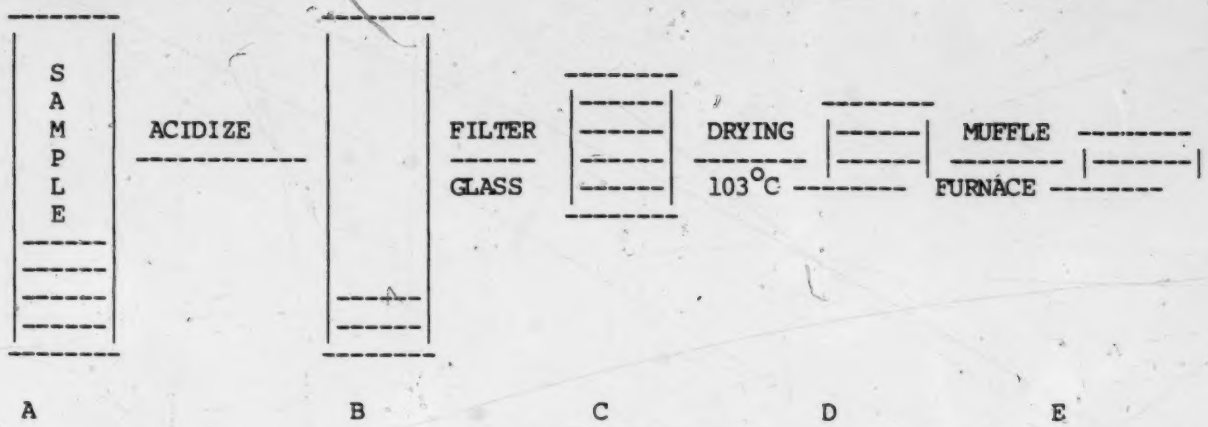
The committee members toured the Mobile Water Treatment Plant.

2.04 Adjournment

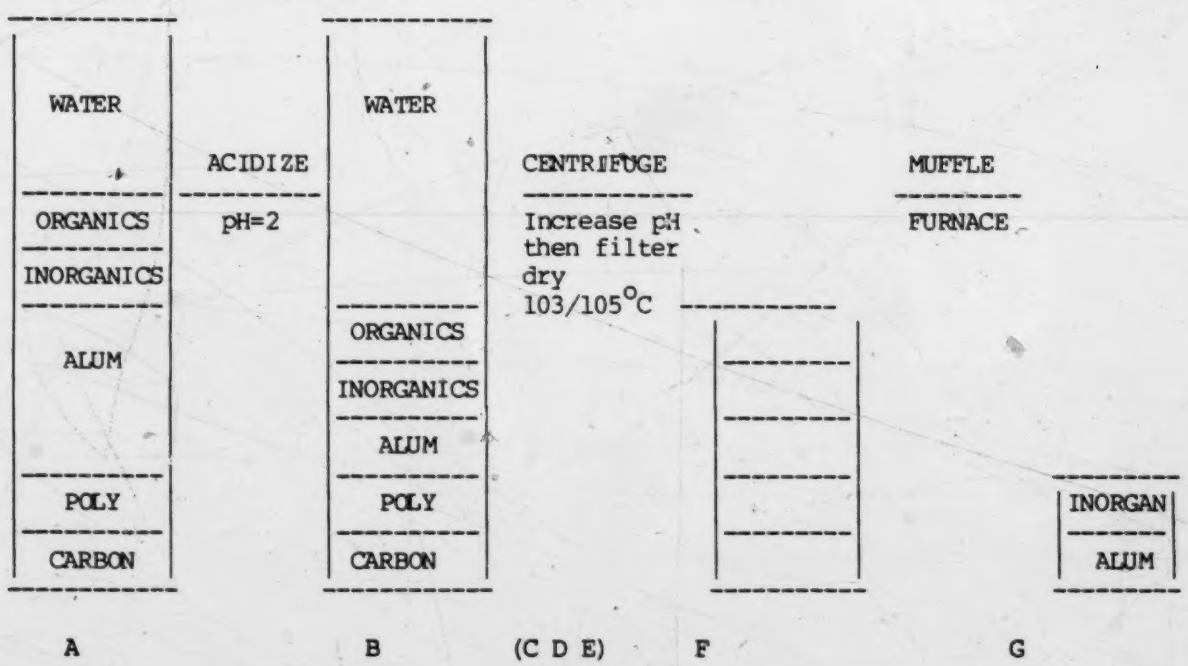
The meeting was adjourned at 16:45 hours. The next meeting is scheduled for Thursday, January 21 at 14:00 hours in the E.L. Smith Plant boardroom.

ANALYTICAL PROCEDURE

AVR PROCEDURE TO DATE



P. HUCKS CONCERNS AND MODIFICATIONS



F-G = POLY + ORGANICS + CARBON

$TOC_{inf} - DOC_{eff}$ = organic carbon removed in clarifier

Also CARBON >> POLY

Therefore, F-G-(TOC-DOC) = CARBON

Plus comparison with
control clarifier.

E.L. SMITH WATER TREATMENT PLANT

PROJECT SCHEDULE

NO.	ACTIVITY	NOV 87	DEC 87	JAN 88	FEB 88	MAR 88	APR 88	MAY 88	JUNE 88	JULY 88	AUG 88
1	Pilot Plant Arrival and Hook-up	****									
2	Commission Plant		****	**							
3	Develop Carbon Analysis Procedure	**	****	****							
4	Experiment 1			****							
5	Experiment 2				***						
6	Experiment 3				*	**					
7	Experiment Spring Runoff					**	**				
8	Experiment Spikes						**	*			
9	Lab Analysis Isotherms/Carbon				****	****	****	**			
10	Data Analysis							**	**		
11	Report Preparation								**	****	****
12	Thesis Submittal										
13	Steering Committee Meetings		*	*	*	*	*	*	*		*

* Each star represents one week

LAST UPDATE: 12/22/87

PAC PILOT PLANT STUDY

STEERING COMMITTEE MEETING NO.3

January 26, 1988 14:30 Hours

PRESENT:	A. Van Roodselaar	- Alberta Environmental Centre (AEC)
	P. Huck	- University of Alberta
	D. Murdoch	- City of Edmonton (Water Treatment)
	K. Kassam	- City of Edmonton (Water Treatment)
	D. Poole	- City of Edmonton (P.D.T.)
COPIES TO:	All Present	B. Gray
	A. Davies	R. Shariff

3.00 Review of Previous Meeting Minutes

1.01 Start-Up Schedule

K. Kassam had revised the schedule to reflect delays. The plant start up and commissioning had commenced.

CLOSED

1.02 Pilot Plant Commitments

A. Van Roodselaar's memo to confirm period of study and availability of M.W.T.P. sill outstanding.

ACTION: A. Van Roodselaars

1.03 Analytical Procedures

1) A. Van Roodselaar (AVR) reported that after a few modifications to the procedure, Frank Skinner had managed to come up with a reliable procedure for determining carbon in sludge. (i.e. ± 10% accuracy) AVR to submit new written procedure for Steering Committee members. K. Kassam to prepare E.L. Smith lab to carry out analysis.

   ACTION: A.V.Roodselaar/K. Kassam

2) P.Huck confirmed that the TOC and DOC sample can and should both be carried out by the University. K. Kassam to report on exact number of samples when plant is up running ready for experiments.

   ACTION: P. Huck / K. Kassam

1.04 Isotherm Derivation

In view of the high costs incurred for isotherm analysis and for experience, K. Kassam offered to volunteer his services to conduct isotherm analysis. P.Huck to respond after consulting with B. Andrews on training and time requirement. AVR and D. Poole may consider sending staff from their areas for this training also; they will confirm next meeting.

ACTION: P.Huck / A.V.R. / D.Poole

1.05 Additional Analysis

Spiking analysis will be carried out by AEC as proposed previously. However AVR to discuss with Dean Smillie the determination of contaminant adsorbed by carbon. P.Huck will also consult with B. Andrews on the subject. In terms of the overall project this information will be given low priority.

ACTION: A.V.R./P. Huck

1.09 Pilot Plant Equipment

All equipment with exception of about $2000 worth of rapid mixers has ~~not~~ been received. The new delivery schedule is for early part of February, 1988.

CLOSED

02 Plan and Budget

K. Kassam had prepared a statement on costs incurred to December 31, 1987 by the City on the project. Also committed costs to date. A copy of the cost summary is attached with the minutes. K. Kassam will not have the experimental plan ready until the clarifiers are up and running.

ACTION: K. Kassam

3.00 NEW BUSINESS

3.01 Study Scope and Priorities

On the basis of the delays encountered to-date, D. Murdoch expressed some concern on the scope of the study. A discussion among members concluded that the following objective one (1) would be the required priority.

1) Establish the means of creating one or more stable and reproductive level of PAC accumulation in a slurry recirculatory clarified blanket using a pilot scale mobile water treatment plant.

If time permits the remaining two objectives will be carried out in the order they are mentioned below:

2) Plant scale spiking of Chloroform to compare clarifier performance.

3) Conduct bench scale isotherms of accumulated Carbon at various stages of the experiment.

3.02 Operator Assistance

In view of increased work load on Riyaz Shariff (AEC provided operator). K.Kassam offered the service of a relief operator at the plant who can assist Riyaz while carrying out the centrifuging duties.

ACTION: K. Kassam

3.03 TON

It was reported that the PDT team had plans to establish TON monitoring program for the spring. K. Kassam suggested that incorporating some TON sampling as part of the study would be of benefit. D. Poole felt adding a couple of samples a day would not be a problem. K. Kassam and D. Poole will work out details.

ACTION: K. Kassam / D. Poole

3.04 Pilot Plant Operations Update

K. Kassam reported that at the present two problems had been encountered with the commissioning of the plants.

1) The forming of the initial sludge blanket was very difficult due to lack of turbidity in raw water. As a result high amounts of Alum carry over was experienced and turbidities of 8-12 NTU were experienced in clarifier effluent. To address the difficulties bentonite had been purchased and solution made up to provide the blanket. In addition Poly Aluminum Chloride addition in one clarifier had shown excellent performance within minutes of its addition. The addition of PACL during start up will also be considered.

2) The second problem was the monitoring of sludge (draft) sample points. Some of the lines were not supplying good flow and steps were being taken to alleviate the problem. This may necessitate emptying of the clarifier and examination of plug up problems in the lines.

K. Kassam also reported that all other aspects of the plant were in good operation and plans were underway to conduct dye studies as soon as the process stabilized. P.Huck advised that this be carried out after the sludge blanket had been established. K. Kassam was

also working on log books for gathering data during the study period.

The above report concluded with a brief discussion on flow characteristics of the pilot scale clarifier and the plant scale clarifier. D. Poole invited some ideas to consider when he designs the clarifiers for PDT pilot plant.

3.05 P.Hucks visit to Illinois

P.Huck reported that he had plans to visit V. Snoeyink next month and would like detailed information on our procedure and clarifier drawings to compare notes with Prof. Snoeyink. K. Kassam to supply clarifier drawings. AVR to supply carbon procedure.

ACTION: K. Kassam/A.V.R.

The meeting was adjourned at 1630 hours. A thirty minute visit to the pilot facility to see the operation was carried out after the meeting. The next meeting will be held at 14:15 hours on Thursday, February 18, 1988, at E.L. Smith Water Treatment Plant Boardroom.

PAC PROJECT

EDMONTON WATER AND SANITATION COST BREAKDOWN

Maintenance Labour	$ 2,350.00
Material (Maintenance)	2,036.00
Material (Operations)	11,175.00
Contract Work	1,910.00
Transformal Rental	324.50
Miscellaneous Costs	50.00
Total Costs to 31 December 1987	$ 17,845.00

* $10,000.00 For original material supplied towards MWTP.

Additional Committed Costs

CHEMICALS	
ALUM	1,000.00
CARBON	300.00
BENTONITE	100.00
MATERIAL	500.00
TRANSFORMER RENTAL	1,000.00
MAINTENANCE LABOUR	200.00
	3,100.00

PAC PILOT PLANT STUDY

STEERING COMMITTEE MEETING NO.4

February 18, 1988 14:15 Hours

PRESENT:	A. Van Roodselaar	- Alberta Environmental Centre (AEC)
	P. Huck	- University of Alberta
	D. Murdoch	- City of Edmonton (Water Treatment)
	K. Kassam	- City of Edmonton (Water Treatment)
	D. Poole	- City of Edmonton (P.D.T.)
COPIES TO:	All Present	B. Gray
	A. Davies	R. Shariff

3.00 Review of Previous Meeting Minutes

1.02 Pilot Plant Commitments

A. Van Roodselaar's memo to confirm period of study and availability of M.W.T.P. sill outstanding.

ACTION: A. Van Roodselaar

1.03 Analytical Procedures

1) New carbon procedure submitted to all present. Procedure attached with minutes. P. Huck impressed with results. Would like two extremes tried, i.e. 2000 mg/L and 10 mg/L to see reproducibility. Albert Van Roodselaar to follow up also K. Kassam to see if R. Shariff could do these on site.

ACTION: A.V.Roodselaar/K. Kassam

2) TOC and DOC sampling schedule not available due to Pilot Plant delay in start up. Will follow up next meeting.

ACTION: P. Huck / K. Kassam

1.04 Isotherm Derivation

P. Huck asked Karim Kassam to call Bob Andrews on arrangement of isotherm derivations.

ACTION: K. Kassam

1.05 Additional Analysis

Little progress has been made on determination of contaminant on adsorbed carbon. Will discuss further at the next meeting.

ACTION: A.V.R./P. Huck

1.09.02 Plan and Budget

Budget submitted last meeting. Plan can still not be derived until Plant is up and running smoothly.

CLOSED

3.01 Study Scope and Priorities

For information purpose, the following decided objectives will remain on the meeting minutes:

1) Establish the means of creating one or more stable and reproducible level of PAC accumulation in a slurry recirculatory clarified blanket using a pilot scale mobile water treatment plant.

If time permits the remaining two objectives will be carried out in the order they are mentioned below:

2) Plant scale spiking of Chloroform to compare clarifier performance.

3) Conduct bench scale isotherms of accumulated Carbon at various stages of the experiment.

3.02 Operator Assistance

Both AEC and City have now provided additional assistance on the Pilot Plant operation.

CLOSED

3.03 TON

On the basis of the work load, TON sampling may be difficult. The item is not at a stage where the TON analysis are necessary but will be considered next meeting.

ACTION: Steering Committee

3.05 P.Hucks visit to Illinois

Drawings and procedures for P. Huck visit where made available. P. Huck will report on visit next meeting.

ACTION: P. Huck

4.0 NEW BUSINESS

4.01 Pilot Plant Operational Update

K. Kassam reported the following on the above subject.

1) Soon after the last meeting, during the cold spell, freeze up of piping in the pilot plant was experienced. This was due to an operator error. Most of the repairs to the cracked piping had since been carried out including the replacement of the sludge pump. This incident caused a 2 week delay.

2) R. Shariff, Plant Operator, was sick for one week after the freezing incident. While no delays can be attributed directly to this, due to overlap with the freezing incident, a concern was expressed in future operation of the Plant. Additional staffing had since been addressed to provide back up coverage.

3) At one of the Operations meetings, commissioning of carbon system was suggested. The operation of this system had caused 2 problems. Sticky float due to carbon deposits on float system, and pump plugging problems. Both these problems were being addressed and K. Kassam will report next meeting.

4) Difficulty with establishing a reliable floc still appears to be a problem. The bentonite/Aluminex floc sometimes is to light. The loss of newly created floc in clarifier-2 was experienced overnight. The computer had shown a 3-4 hour high turbidity >10 in clarifier effluent overnight. Plant operators to investigate if drain system leak may have caused this. A.V.R. would like to see a reproducible recipe of floc formation prior to experimental runs.

ACTION: K. Kassam

5) K. Kassam reported that the use of Aluminex had proven to be more efficient then Alum. However, at Plant scale (E.L. Smith) the switch from Aluminex to Alum had shown just as good a performance. P. Huck said that we should try and maintain the same conditions at pilot level as those in Plant. K. Kassam was asked to use Aluminex to form a good floc then switch to Alum and compare performance. If Alum does not perform well, then a switch back to Aluminex can be made.

ACTION: K. Kassam

6) The rapid mixers had now arrived and installation will shortly proceed. P. Huck asked K. Kassam to look into optimizing the speeds of rapid mixers.

ACTION: K. Kassam

7) Most of the lab equipment for carbon analysis had arrived on site. The muffle furnace 220V plug-in is required before the lab is set up to carry out carbon analysis. K. Kassam will have R. Shariff set up by next meeting.

ACTION: K. Kassam

8) Strontium Chloride tracer study through one clarifier had been carried out to provide preliminary data. K. Kassam to report back next meeting.

ACTION: K. Kassam

4.02 Plant to Pilot Scale Comparisons

B. Gray had prepared some comparative data for the two Plants (see Attachment). It appears that the Pilot Plant is having some difficulties operating at hydraulic capacity under cold water conditions. In terms of clarifier performance, comparable performance appears to be attained when Pilot Plant runs at rise rates of 5 cm/min compared to full scale plant at 7.5 cm/min. K. Kassam will have more data at next meeting.

ACTION: K. Kassam

The meeting was adjourned at 16:30 hours. A quick visit to the facility by some members of the Committee followed. The next meeting is scheduled for Thursday, March 17, 1988, at 14:00 hours.

PAC PILOT PLANT STUDY

STEERING COMMITTEE MEETING NO.5

March 17, 1988 14:00 Hours

PRESENT:	A. Van Roodselaar	- Alberta Environmental Centre (AEC)
	P. Huck	- University of Alberta
	K. Kassam	- City of Edmonton (Water Treatment)

COPIES TO:	All Present	B. Gray
	A. Davies	R. Shariff
	D. Murdoch	D. Poole

5.00 Review of Previous Meeting Minutes

1.02 Pilot Plant Commitments

Letter of confirmation on the Pilot Plant Commitments was submitted at the meeting.

CLOSED

1.03 Analytical Procedures

1) R. Shariff had attempted to analyze carbon at two extreme concentrations. However, he had experienced difficulties with low concentrations. A 50 mg/L error appeared to exist at all concentrations. The nature of the new carbon, only 65% volatilized in muffle furnace compared to 94% with previous carbon. A.V.Roodselaar to get Environmental Centre to conduct the analysis. In the meantime, K. Kassam to continue attempting the analysis through R. Shariff to see if some fine tuning can be done.

ACTION: A.V.Roodselaar/K. Kassam

2) TOC and DOC sampling schedule still outstanding.

ACTION: P. Huck/K. Kassam

1.04 Isotherm Derivation

K. Kassam had not been able to get in touch with Bob Andrews. He'll do so as soon as possible and report back next meeting.

ACTION: K. Kassam

1.05 Additional Analysis

No progress has been made on determination of contaminant on adsorbed carbon. To be discussed next meeting.

ACTION: A.V.R./P. Huck

3.01 Study Scope and Priorities

1) Establish the means of creating one or more stable and reproducible level of PAC accumulation in a slurry recirculating clarifier blanket using a pilot scale mobile water treatment plant.

If time permits and possibly under Process Development Team's direction, the following two objectives will be carried as part of this study:

2) Plant scale spiking of Chloroform to compare clarifier performance.

3) Conduct bench scale isotherms of accumulated Carbon at various stages of the experiment.

3.03 TON

TON analysis does not appear to be able to carry out due to manpower requirements. PDT to confirm next meeting.

ACTION: D. Poole

3.05 P.Hucks visit to Illinois

P. Huck discussed his meeting with V. Snoeyink. Prof. Snoeyink's study is making a slow progress and his findings appear to be focusing on the effects of chemical feed points, PAC particle size and blanket depth on performance in organic removal.

INFORMATION

4.01(4) Floc Formation Recipe

R. Shariff had been successful in developing a reproducible recipe of creating floc blanket in the clarifier. A copy of this is attached with the minutes. This recipe will mean quick reestablishment of floc between experimental runs.

CLOSED

4.01(5) Alum/Aluminex

Attempts to switch from Aluminex to Alum were not successful. At a flow of 150 LPM, a switch from Aluminex 18 mg/L and Poly 0.17 mg/L to Alum 50 mg/L and Poly 0.20 mg/L, turbidity increased after one (1) hour, so poly feed was increased but performance deteriorated steadily over 2 days. Turbidity of

over 20 NTU's were experienced during this period. A switch back to Aluminex restored performance. Aluminex use through the experience was confirmed.

CLOSED

4.01(6) Rapid Mixers
Rapid mixers could not be tested due to repeated tripping (power interruption). It was later realized that the trips were a result of overload protection on the panel. Installation of thermal overload protectors were underway and rapid mixers would be in operation soon.

ACTION: K. Kassam

4.01(7) Lab Set-up
Lab had been set up with 220 Volt plug in now made available.

CLOSED

4.01(8) Strontium Chloride Tracer
Strontium Chloride Tracer study had been carried out but the peak had failed to be reached during the sampling (see Attachment). A second attempt on Tracer, this time with extended length will be carried out by March 25, 1988.

ACTION: K. Kassam

4.02 Plant to Pilot Scale Comparison
In view of the improved floc formation now developed, the pilot plant performance figures are now revised to reflect improved performance. The pilot plant performance is now comparable to full scale (see Attachment).

CLOSED

5.0 NEW BUSINESS

5.01 Pilot Plant Operational Update

1) Muffle Furnace
An unfortunate incident in which the furnace had been left at high temperatures for an extended period had resulted in the damage to one of the four heating elements. Arrangements are being made to replace the element as soon as possible but it looks like at least a four week delivery time.

ACTION: K. Kassam

2) Carbon System
A test on the carbon feed system proved to be extremely valuable. The float system was replaced after the old system

had problems with sticking. The pumps were also jamming too frequently. The use of little giant pumps was found to be more appropriate. Also an automatic solenoid flush system is planned to be installed to avoid build up and ensure reliable operation during experimental runs.

ACTION: K. Kassam

3) Carbon Analysis

Carbon analysis at E.L. Smith lab showed some problems. There appeared to be a consistent 50 mg/L discrepancy in known samples. Investigations are underway to isolate the problems. Samples will be sent to Vegreville for analysis to confirm if technique or procedure difficulties are contributing to the problem. K. Kassam to also get the weighing balance recalibrated.

ACTION: A.V.R./K. Kassam

5.02 Experimental Runs

With most of the outstanding work scheduled for completion prior to March 27, an experimental run can commence in the first week of April. It was decided that the first run be carried out at carbon feed of 10 mg/L. Assuming 1000 mg/L PAC accumulation in sludge, about 24 hours of feed at 150 LPM would be required (assuming no draining). A minimum 3 day experimental run was selected. Sampling in experimental clarifier will be done every hour while control clarifier every 3 hours. Drain samples will also be done when required. Not all samples collected will be required to be analyzed. Depending on carbon accumulation rates, the samples will be selected for analysis.

ACTION: K. Kassam

The meeting was adjourned at 16:00 hours. The next meeting is scheduled for Tuesday, April 19, 1988, at 14:00 hours.

Alberta
ENVIRONMENTAL CENTRE

BAG 4000, VEGREVILLE, ALBERTA T0B 4L0

403 / 632-6761

File No. 2440-CS8-3

March 17, 1988

Mr. Doug Murdoch, P.Eng.
Director, Water Treatment Plants
Edmonton Water and Sanitation
12220 Stony Plain Road
EDMONTON, Alberta
T5N 3Y4

Dear Mr. Murdoch:

Subject: PAC Project at E. L. Smith

Further to our discussions regarding the joint undertaking of a study on powdered activated carbon utilization within a modern recirculation clarifier system, I would like to convey our current position. I feel that within the context of our intent a worthwhile project is possible based on your ability to provide certain support. Specifically, we will provide the test unit (MWTP) from mid-October to May 31, 1988. Based on our current plans, this would provide adequate test time. In support of this, you have agreed to provide a minimum of $10,000 to allow me to purchase auxiliary equipment necessary for plant operation. Possible extension of this period to the fall of 1988 may be possible dependent on the time schedule for our other commitments and the results and funding developments for the project.

We will provide an operations person for the period of November 1, 1987 to April 30, 1988 (with a portion of a second operational person during this period). In addition, we will provide engineering support as supplied by B. Gray for system debugging, start-up and operation.

I have arranged analytical support (GC-MS) for the project with our Organic Analysis Group. Approval for 40 to 50 samples currently exists. Development of a procedure for accumulated carbon analysis will be developed at AEC and the operational measurements will be undertaken by Pilot Plant Operations staff (AEC's manpower contribution stated above) using laboratory space and equipment supplied by the City of Edmonton and located at E. L. Smith.

I understand that an additional portion of the operational manpower is to be supplied by the City. Chemical, supply and operational cost will be the responsibility of the City. Also, maintenance and instrumentation support would be provided by City staff on-site.

...2

I look forward to carrying this project to a successful conclusion based on this understanding.

Yours truly,

A. van Roodselaar, Ph.D., P.Eng.
Head, Operations Group
Environmental Technology

AvR/clg
0976C

PAC PILOT PLANT STUDY

STEERING COMMITTEE MEETING NO.6

April 19, 1988 14:30 Hours

PRESENT:	A. Van Roodselaar	- Alberta Environmental Centre (AEC)
	P. Huck	- University of Alberta
	D. Murdoch	- City of Edmonton (Water Treatment)
	D. Poole	- City of Edmonton (PDT)
	K. Kassam	- City of Edmonton (Water Treatment)
COPIES TO:	All Present	B. Gray
	A. Davies	R. Shariff

6.00 REVIEW OF PREVIOUS MEETING MINUTES

1.03 Analytical Procedures

1) After various carbon samples were analyzed, the final choice of the carbon was that supplied by Mackenzie and Feimann and it volatilized at 82%

CLOSED

2) TOC and DOC sampling will be done in conjunction with isotherm derivations.

ACTION: P. Huck/K. Kassam

1.04 Isotherm Derivation

K. Kassam had discussed with Bob Andrews and confirmed that an isotherm analysis can be carried out in one week. It was proposed that after the maximum concentration in slurry blanket is established, isotherm analysis can be carried out on these samples. Karim to finalize the arrangement with B. Andrews.

ACTION: K. Kassam

1.05 Additional Analysis

Determination of contaminant on adsorbed carbon will now be addressed under Phase II of this project by the PDT Group.

CLOSED

3.01 Study Scope and Priorities

Objective 1: Same as those reported last meeting.

Objective 2: Plant scale spiking of organics will now be considered by PDT.

Objective 3: Bench scale isotherms may be carried out if K. Kassam can arrange it with B. Andrews.

3.03 TON

It was decided that TON analysis will not be carried out under the scope of this study.

CLOSED

4.01(6) Rapid Mixers

While the thermal overload protectors had been installed and rapid mixers did become operational, an opportunity to find their optimal speed had not been found. P. Huck would still like to see this done before the next run.

ACTION: K. Kassam

4.01(8) Strontium Chloride Tracer

The second attempt to carry out the tracer studies had been completed. The results were not available for discussion, but K. Kassam will incorporate the plots with these minutes (see Attachment III and IV). To be discussed next meeting.

ACTION: Steering Committee

5.01(1) Muffle Furnace

The elements had been installed prior to commencement of Experimental run #1.

CLOSED

5.01(2) Carbon System

With almost 144 hours of run time on experiment #1, no problems with the carbon feed system were experienced. The modifications had proved to have worked.

CLOSED

5.01(3) Carbon Analysis

Problems encountered in performing carbon analysis at the E.L. Smith site were solved. The problem was the contamination of the reagent grade sulfuric acid that contributed to the discrepancy.

CLOSED

5.02 Experimental Runs

As planned the first experimental run had been completed. K. Kassam presented some initial results for the Committee's review. The discussion is covered under New Business section of these minutes.

CLOSED

6.0 NEW BUSINESS

6.01 EXPERIMENTAL RUN NO.1

Preliminary results of experimental run #1 were presented to the Committee (see Attachment I).

Synopsis of Results:

At flow rate of 150 LPM and 10 mg/L of carbon feed, a peak of just over 600 mg/L was reached in about 57 hours. Sudden high turbidities and draining appeared to have hindered the accumulation. High concentrations of PAC (1,400 - 2,000 mg/L) were analyzed in the drain samples. Towards the end of the run, an 80 mg/L carbon feed caused the carbon concentration in the slurry to peak at 2000 mg/L after 24 hours. The run was then terminated.

Variables:

From the results, it appears that recirculator speed, draining, incoming turbidity, and carbon feed concentrations are contributing factors in the accumulation and suspension of PAC in the slurry blanket. These variables need to be looked into in detail in the next sets of experiments.

Carbon Derivation:

K. Kassam outlined the method used to derive concentration of carbon in sludge sample on the basis of the analysis (see Attachment II).

Mass Balance:

To confirm the accumulation of carbon, it was decided that an overall mass balance on the clarifier be carried out from T=0 to T=60 hours. K. Kassam will report back next meeting.

ACTION: K. Kassam

6.02 EXPERIMENT RUN NO.2

On the basis of experiment #1 results, the Committee decided to duplicate the same conditions for experiment #2 and see if the results can be replicated. Experiment #2 will be carried out in two phases:

Phase 1: Feed 10 mg/L of carbon
Keep all chemical feeds, recirculator speed, and flow, and if possible draining routines similar to run #1. After 60 hours, phase 1 is complete. Sampling will be carried every 3 hours and analyzed every six hours.

Phase 2: Continue same conditions as Phase 1 with the exception of recircular speed. Increase speed for 36 hours then reduce back to normal for 36 hours. Follow sampling and analysis routine as per phase 1.

Experiments 3 and 4 will be discussed at the next meeting.

6.03 SCHEDULE

With the May 31 deadline approaching, the Committee reviewed the schedule with a view to fit in at least 3 more experimental runs. The following schedule of activities was agreed:

Week of:	Activity
April 25	Startup / Analysis
May 2	Experiment #2
May 9	Shutdown / Startup / Analysis
May 16	Experiment #3
May 23	Shutdown / Startup / Analysis
May 30	Experiment #4

6.04 LOST TIME ACCIDENT

K. Kassam reported a second lost time accident this year that took place at the Pilot Plant. Pat Johnson, Operator I, was sampling during experimental run #1 when she rolled over filled sample bottles on the walkway. She lost balance and fell between the clarifier #1 and walkway. She appears to have injured her lower back. The Committee members visited the Plant to view the site. City/AEC will consider extending the walkway in the future.

ACTION: K. Kassam / A.V.Roodselaar

6.05 PROCESS DEVELOPMENT TEAM (PDT) INVOLVEMENT IN PROJECT

Plans have been worked out between PDT and AEC to carry on with the project after June 1. K. Kassam to recruit R. Shariff as Operator. A.V. Roodselaar looking into the possibility of transferring C. Jardine to AEC for a temporary period. Arrangement will be finalized by next meeting.

ACTION: K. Kassam / A.V. Roodselaar

The meeting was adjourned at 16:30 hours. The next meeting is scheduled for Monday, May 16, 1988, at 14:00 hours.

PAC PILOT PLANT STUDY

STEERING COMMITTEE MEETING NO.7

May 16, 1988 14:00 Hours

PRESENT:	A. Van Roodselaar	- Alberta Environmental Centre (AEC)
	P. Huck	- University of Alberta
	D. Murdoch	- City of Edmonton (Water Treatment)
	D. Poole	- City of Edmonton (PDT)
	K. Kassam	- City of Edmonton (Water Treatment)
COPIES TO:	All Present	B. Gray
	A. Davies	R. Shariff

7.00 REVIEW OF PREVIOUS MEETING MINUTES

1.03 Analytical Procedures

As part of experiment run #4, TOC/DOC analysis will be done for raw water and DOC analysis for effluent. K. Kassam to arrange with P. Huck and R. Andrews.

ACTION: K. Kassam

1.04 Isotherm Derivation

After the Steering Committee meeting, P. Huck, R. Andrews and K. Kassam met and finalized an approach to carry out isotherms. These analyses are scheduled for early June and will be held simultaneously with experiment #4. K. Kassam to arrange to conduct these full time for a 2-week period.

ACTION: K. Kassam

3.01 Study Scope and Priorities

Objective 1: Same as those reported last meeting.

Objective 2: A modified chloroform isotherm on carbon slurries subjected at 2 carbon dosages will be conducted to verify residual carbon capacity.

Objective 3: Chloroform spiking on clarifiers will now be addressed by PDT under Phase II of this study.

4.01(6) Rapid Mixers

Due to time constraints, an experiment to realize the optimal speed of the mixers has not been able to be carried out. PDT can address this in Phase II.

CLOSED

4.01(8) Strontium Chloride Tracer

Results of the last tracer studies were discussed at length. R. Shariff clarified some of the aspects for the committee. It was agreed that to obtain exact detention times in the two clarifiers, a spike rather than the previously used step analysis be conducted. K. Kassam and R. Shariff to organize this. A.V.Roodselaar will arrange analysis of samples collected.

ACTION: K. Kassam / A.V.R.

6.01 Mass Balances

The committee had requested a mass balance on carbon from Experiment #1 be carried out. K. Kassam had done this for both experiments. The results are under Attachment III and a discussion is covered under the New Business section of these minutes.

CLOSED

6.02 Experiment Run No.2

This was carried out as outlined results discussed under New Business.

CLOSED

6.03 Schedule

Due to the extended run of Experiment #2, it now appears that the study completion date will also be extended to June 1988. David Poole saw no real problems with this extension.

Week of:	Activity	Status
April 25	Startup / Analysis	Completed
May 2 & 9	Experiment #2	Completed
May 16	Shutdown / Startup / Tracer	Completed
May 23	Experiment #3	On Schedule
May 30	Shutdown / Startup / Analysis	Proposed
June 6	Experiment #4	Proposed
June 13	End of Phase I study	Proposed

6.04 Lost Time Accident

A railing to isolate the walkway has been completed. Sampling bottles are now being stored inside the clarifier building. Pat Johnson is now back working.

CLOSED

7.00 NEW BUSINESS

7.01 EXPERIMENT RUN NO.2

Experiment #2 was carried out in the following manner.

Part I: 10 mg/L carbon feed. For the first 60 hrs., the clarifiers were subjected to the same conditions as Experiment #1, i.e. RPM chemical feeds, draining, etc. Attachment I shows results of the 60 hr. run and compares with Experiment #1. A very similar performance was observed confirming the reproducibility of the carbon accumulation under similar conditions.

Part II: 10 mg/L carbon feed continued but all other parameters were changed to provide optimum clarifier performance. The idea was to reach a plateau of carbon concentration in the center zone. After approx. 120 hrs. (180 hr. from start) the carbon concentration had reached 1500 mg/L and still rising (Attachment I). Bearing in mind that the raw water turbidities had stayed consistent at 8-10 NTU, minimum draining was required. (In Experiment #1, turbidity increased to 250 NTU after 60 hrs. of operation).

Part III: All parameters were kept similar to Part II with the exception of recirculator speed. For the first 24 hrs., the RPM were increased from 13.5 to 19 and then for the next 24 hrs. reduced back to 13.5 RPMs. As shown in Attachment I, no real impact on carbon concentration in the inner zone was noticed. After 220 hrs. of operation, about 1800 mg/L carbon concentration was observed and it appeared to have stabilized but the experiment was terminated shortly after.

7.02 MASS BALANCES

Attachment III summarizes the mass balances on carbon for the two experimental runs. The balance assumes 0 mg/L carbon concentration in clarifier effluents. The concentrations observed in inner zone appears to be slightly higher than the theoretical concentration of carbon present in the entire clarifier volume. In Experiment #2, approximately 30-35% of total carbon was consistently observed in the inner zone.

The Steering Committee recommended that the following aspects be examined closely:

1) Carbon in Effluent:
That the amount of carbon in the effluent be quantified by using the micropore filter and drying technique.

2) Homogenize / Mass Balance:
To confirm the exact concentration of carbon present in the clarifiers, at the end of an experimental run complete mixing of the clarifier using recirculation, and air be tried and samples analyzed for carbon concentration.

Action: K.Kassam

3) Carbon Profile:
During experimental run, samples of carbon outside the inner zone (settling zone) be obtained to give some idea of the sludge bed profile in the clarifier.

Action: K.Kassam

7.03 SUMMARY OF RESULTS TO DATE

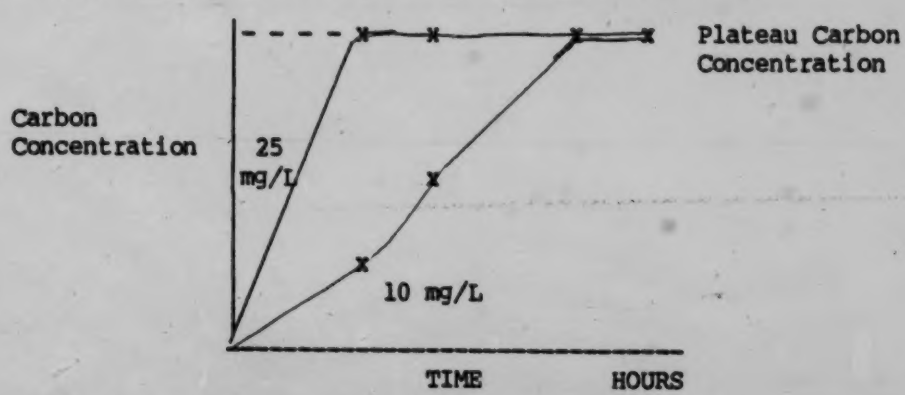
The Steering Committee summarized the following conclusions from the study to date:

1) The two clarifiers are comparable in performance.
2) Carbon accumulation in clarifier is reproducible.
3) The recircular speed has no impact on carbon concentration in normal mode of operation.
4) From the mass balance, it appears that the distribution of carbon in the clarifier is uniform.
5) That the plateau concentration of carbon in the clarifier sludge is close to 2000 mg/L.

7.04 FUTURE EXPERIMENTS

Experiment #3:
It was proposed that Experiment #3 will be carried out at a carbon feed of 25 mg/L. The experiment will be used to confirm the plateau concentration of carbon in the clarifier sludge and the uniform distribution of carbon in the clarifier.

Experiment #4:
In the final experimental run both clarifiers will be used for experimental run. One with 10 mg/L and the other with 25 mg/L. Carbon isotherms will be carried out at various stages of this run. Figure below provides some idea of expected performance.



x = Proposed Isotherms

Experiment #4 will provide the following information:

1) Confirm the build up of carbon is proportional to feed rate.
2) The residual capacities of carbon under two feed conditions at different time intervals.
3) Do background contaminants interfere with carbon capacity?

7.05 Adjournment

It was decided that in view of the Steering Committee outlining the entire course of the experiments to conclusion of Phase I, that the next meeting be held after all the results are in. The next meeting will most likely be the final meeting of the present Steering Committee before the PDT and AEC put together Phase II of the study.

Next meeting to be held on July 4, 1988 at 1400 hrs. in the E.L. Smith boardroom.

INFORMATION